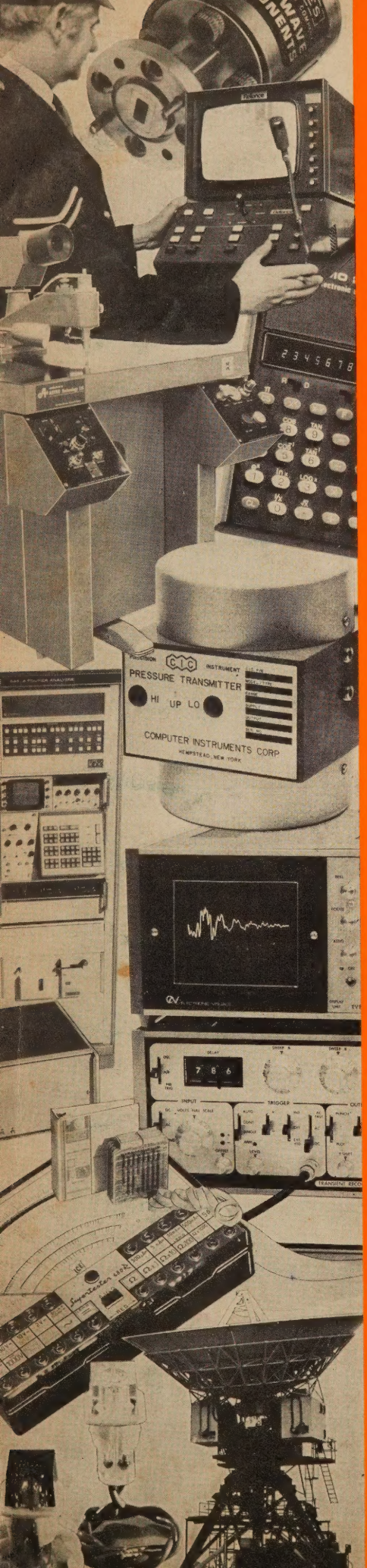

The Radio and Electronic Engineer

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25TH ANNIVERSARY OF THE STORED PROGRAM COMPUTER

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Early Computer Developments at Cambridge University

The Pilot ACE at NPL

Computers in the University of London 1945-1962

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Diversity Techniques for Mobile Radio Reception

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CONFERENCE PROGRAMMES

Hybrid Microelectronics

Instrumentation in Oceanography

THE INSTITUTION

Information on Local Sections and Specialized Groups

Vol. 45, No. 7 JULY 1975

Conference on

'Hybrid Microelectronics'

Organized by THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS in collaboration with The International Society for Hybrid Microelectronics with the association of The Institution of Electrical Engineers, The Institute of Physics, and The Institute of Electrical and Electronics Engineers.

The University of Technology, Loughborough

Tuesday, 9th to Thursday, 11th September 1975

Specific themes for the Conference are as follows:

New materials and techniques

The problem of add-on components

Packaging of hybrid microelectronics

The designing of hybrid microelectronic circuits against problems on testing, reliability, etc.

Applications of hybrid microelectronics in the fields of:

Consumer electronics

High frequencies, including microwaves

Opto-electronics

Education. It is envisaged that this will take the form of a discussion panel on the best way that universities, polytechnics and technical colleges can be teaching the construction and application of circuits, using hybrid microelectronics.

Further information and registration forms for the Conference may be obtained from the Conference Department.

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Volume 45 No. 7 July 1975

The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

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J. D. PARSONS, M.Sc., C.Eng., M.I.E.R.E., **M. HENZE,** M.Sc., **P. A. RATLIFF,** B.Sc., Ph.D., and **M. J. WITHERS,** M.Sc., C.Eng., M.I.E.E.
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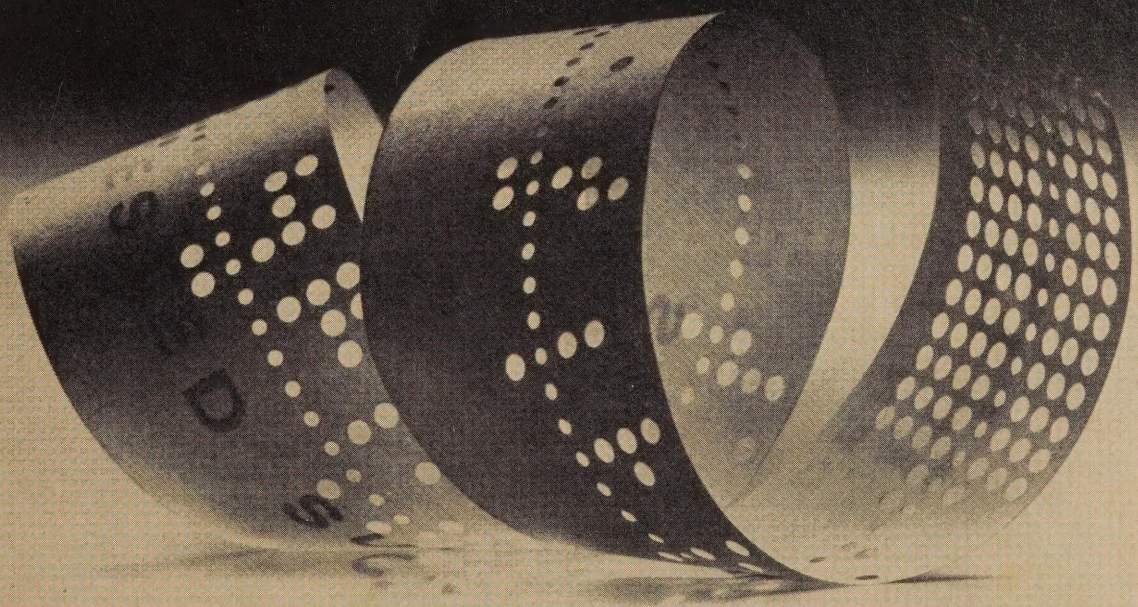

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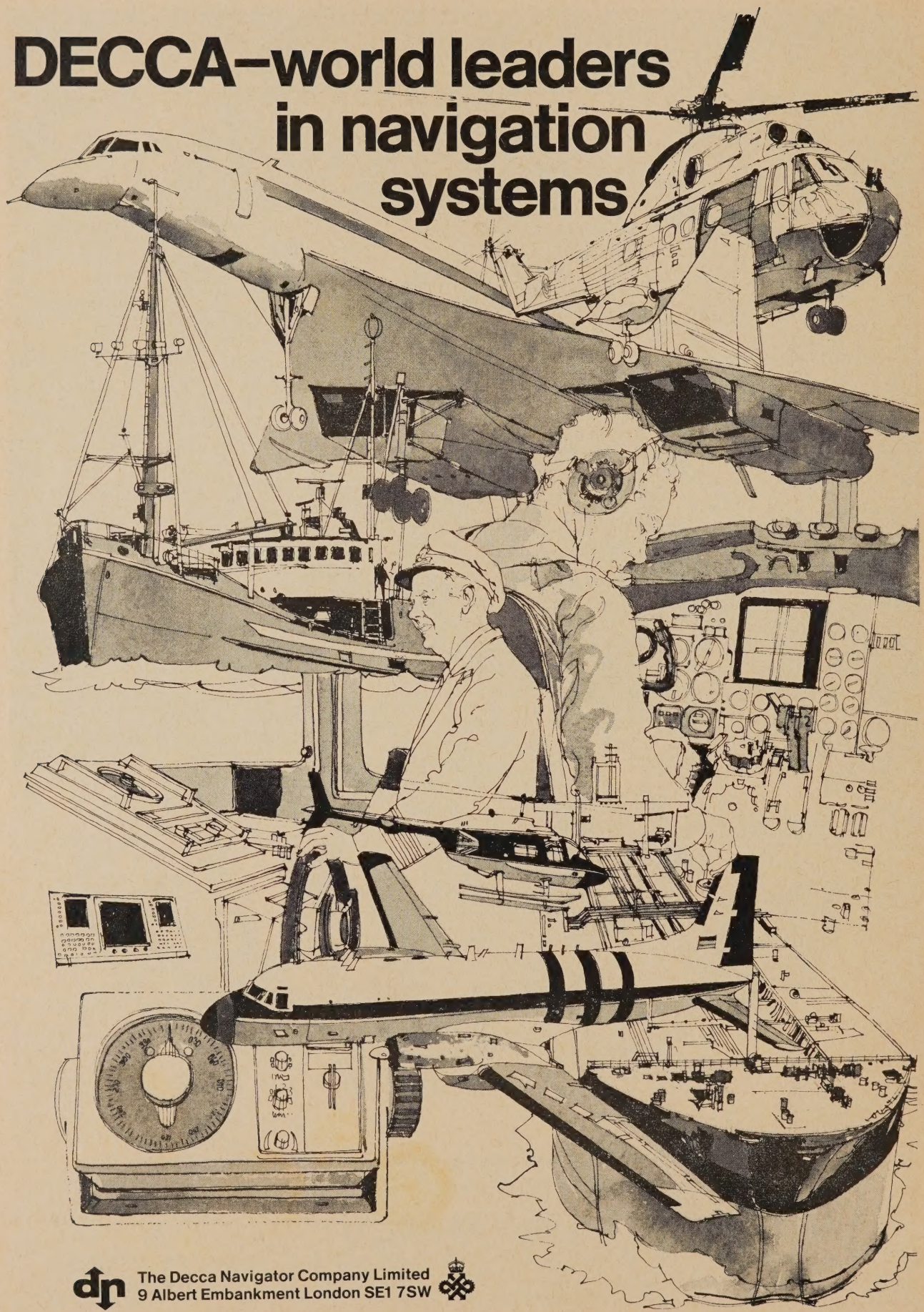

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Communication between all Engineers

CHARTERED Engineers of all disciplines are understandably confused by the piecemeal disclosure of proposals and counter schemes designed to secure better public and Government recognition of the entire engineering profession. The declared purpose of such plans is to achieve parity of employment in engineering with law, medicine, accountancy, etc., where proved academic and practical training and experience are essential elements in securing a licence to practise a *chosen* occupation.

Such commendable objects have become bewildered by a welter of individual, institutional, economic and political interests which obscure the vision of creating the Council of Engineering Institutions just ten years ago as a means of promoting communication between engineers *of all disciplines*. So emphatic was their desire to ensure rapport between different disciplines (as, for example, in the medical profession) that all the Chartered Engineering Institutions supported the petition to the Privy Council for a Royal Charter to CEI.

IERE policy is that the Council of Engineering Institutions must remain as the federal body of different engineering expositions, but must not intrude into the affairs of any constituent member Institution unless the other members of CEI agree that an Institution is neglectful in maintaining standards.

Like the medical profession, engineering has several specializations; there are indeed many specialists within specific areas but this does not gainsay the need to encourage even further development within, for example, the whole area of electronics. The purpose of the IERE is to foster, as a qualifying body and learned society, the evolution of radio and electronic science. The history of technology rejects the idea of an omniscient authority or single Institution.

Individual interests are not decried; it is, however, a fact that no *chartered* Institution shall participate in trade union activities. Correspondence from and meetings of IERE members firmly repudiate any idea of renouncing the Charter in favour of becoming, in any form, a trade union.

If political interest could be channelled into securing recognition of the labour of the chartered engineer in undergoing academic and practical training, Parliamentary legislation might define an 'engineer' as distinct from a technician or craftsman. There could then be an end to quibbles of EEC compatibility and encouragement given to young people and the educational system to adapt courses affording opportunity for efficient services.

At present membership of any Institution and the acquisition of the title 'Chartered Engineer' is voluntary. The subscription paid by all members supports advancement of their particular technology in learned society, educational and similar activities. It is hard to see how this support and dedication to a profession can be extended into personal or trade union activity.

Meanwhile of all the public commentators, Peter Rodgers of *The Guardian* (29th May 1975) most aptly described the problem—'Most architects would probably understand their colleagues' drawings, but there is little chance of a civil engineer understanding the hieroglyphics of an electronic engineer.' Nevertheless, engineers must communicate more with each other wherever there are common problems. Before agreeing to destroy CEI as a federal body they must appreciate the dangers of creating a monolithic and expensive superstructure. The question of providing services of a personal nature suggests however, another society which does not encompass the functions of the Chartered Institutions.

G.D.C.

Guest Editorial

The 25th Anniversary of the Stored Program Computer

LORD BOWDEN, M.A., Ph.D., M.Sc.Tech., C.Eng., F.I.E.E.

Chairman of the Colloquium

The growth of the computer industry has been one of the most spectacular phenomena of the post-war era, and a meeting was held in the Royal Society Rooms on 12th November 1974 to commemorate the twenty-fifth anniversary of the first public demonstration in this country of the stored program computers from which the whole enormous modern industry developed. Most of the men who were in at the very beginning came together to talk about life as it was then. I cannot remember such an exhibition of mass nostalgia.

It is extraordinary to be reminded how few people there were in those days who understood anything about these machines, how few there were who attempted to build them, how impoverished they all were, how inadequately they were equipped, and how ingenious they were in making something out of almost nothing. It is even more remarkable to be reminded once again how hard it was to make the machines work at all, and how unreliable they were when they were coaxed into action. It never seemed possible that they could solve any problems which were long enough to be important, or that there would ever be enough mathematicians to prepare the programs for complicated calculations. If one used the valve manufacturer's own figures, one could show conclusively that two valves were certain to fail in a big machine every hour. We subsequently discovered that British-made valves were more reliable in computers than American valves were, so we corrected our statistical analysis of possible valve failures, and found why our machines were working so well.

Of course relays stuck, and funny things would happen to the electric supply, so the machines made mistake after mistake. It seemed as if there would always be mistakes in the programs too and in the data with which machines had to work. I have never understood why the pioneers were so confident, and so persistent.

The modern computer industry depends on transistors and all kinds of solid-state devices which didn't exist in those days. A friend of mine went to the Bell Labs about twenty-five years ago to see the first transistors in the world. They were expensive and unreliable and very hard to make. He told me, I remember, that the material of which they were made had to be incredibly pure. If some impurities were present to an extent equivalent, he said, to a lump of sugar in a train-load of coal, the transistor was imperfect. He concluded that these new-fangled devices would never be mass-produced, and most certainly that they would never replace the familiar electronic valves. I don't think that a valve version of *Atlas* would be much more promising than an all-mechanical 'Babbage-like' version of the machines which burst on the world twenty-five years ago.

I must complete the story by saying that after Ferranti had built a commercial machine for Manchester University I was asked to decide if more machines should be built, or would ever be needed in this country. I talked to Professor Douglas Hartree, who knew as much about the subject as any man alive. He told me that all the calculations that would ever be needed in England could be done on the three machines which were then being built, in Cambridge, in Manchester and in the National Physical Laboratory. He strongly advised Ferranti to get out of the computer business, or they would lose a great deal of money. In the end, and as things turned out, Hartree was right, because Ferranti did lose money by making computers. I had the very difficult task of finding customers who were prepared to pay to have their calculations done quickly and automatically on a machine, the very existence of which astonished them.

I think it is important to try and set the scene. The events which the meeting discussed took place long before anyone had the slightest idea of the computer revolution. These were the days *before* I.B.M. The crystal ball was very clouded indeed. The pioneers built better than they knew, they were all very remarkable men, the country owes them much, and it was altogether fitting that they should be paraded before the young men who take everything they did for granted and earn their living today by using techniques which have advanced in twenty-five years more dramatically than our powers of locomotion advanced between the stage coach and the moon rocket.

There must have been giants in those days, and most of them came to London to tell us how they did it. But we shall never really know why.

Lord Bowden has been Principal of the University of Manchester Institute of Science and Technology since 1964. He is a graduate of Cambridge University and during the war was engaged on radar research. He was with Ferranti Ltd. from 1950 to 1953 and in 1953 was appointed Dean of the Faculty of Technology of the University of Manchester. Lord Bowden was chairman of the Electronics Research Council of the Ministry of Aviation from 1960 to 1964 and Minister of State at the Department of Education and Science from 1964 to 1965.

Early computers at Manchester University

Professor F. C. WILLIAMS, C.B.E., D.Sc., D.Phil., F.R.S., C.Eng., F.I.E.E.

Presented at the Colloquium on the 25th Anniversary of the Stored Program Computer, held at the Royal Society, London, on 12th November 1974

It is fairly easy by reference to such records as survive to describe what had been achieved twenty-five years ago. What is difficult is to recreate the environment of uncertainty and excitement in which those achievements occurred. After the event it seems absurd that there could ever have been any doubt as to the viability of the stored program computer. The principle was obviously sound and all that was needed was to assemble the appropriate bits, wire them up, and off you go.

Before the event the situation was different. There was no storage system in existence that was known to work with the reliability and freedom from errors that would be required. Thermionic valves had hardly ever been assembled in one equipment in the numbers that would be required. In practically every application of valves to date absolute freedom from malfunction had been unnecessary. In communication a missed word could be repeated. In radar if you missed one echo you would probably get the next. It was well known that when electronic equipment failed to function a well placed kick would often cure it. In equipment devoid of memory the post-kick condition was acceptable, in a device with memory it would be useless.

Perhaps most important of all is the fact that if you go to the holders of the purse strings with a proposition that is obviously going to work, but as yet has not, you will experience difficulty in extracting money. If you have a working model and can demonstrate rather than persuade your position is infinitely stronger.

The fact that these uncertainties did exist may be established by reference to Professor M. H. A. Newman's contribution to the Royal Society discussion on computers in March 1948.[1]

> 'No real machine can be truly universal because its size is limited—for example, no machine will work out π to 10^{1000} places of decimals because there is no room in the world for the working or the answer; but subject to this limitation of size, the machines now being made in America and in this country will be "universal"—*if they work at all*; that is, they will do every kind of job that can be done by special machines.'

Evidently in 1948, incredible as it may now seem, the 64 dollar question was still 'if they work at all'. It was this environment of uncertainty that generated the very real excitement surrounding the events to be described by me and by my fellow contributors to this meeting.

My title was very carefully chosen in that it refers to computers *at* Manchester University rather than *by* Manchester University and reflects the fact that we had much assistance from other bodies.

My interest in computers began at TRE (see Fig. 1) and was directly caused by the atom bomb. Substantially overnight this event converted a mass of radar experts with endless problems for which they were seeking solutions, into a mass of experts with endless solutions and no problems, for in those days we were naive enough to believe that the end of war meant the beginning of peace.

Computers seemed a promising field. I never was, never have been, and never will be a mathematician. I did not even know there was any system of numbers other than the scale of ten, but when the specification of a storage system was explained to me I could grasp what was wanted.

The cathode-ray tube storage system was the outcome. When I left TRE and moved to Manchester in late 1946, it had reached the state where 1 c.r.t. could store 1 binary digit. After the move, TRE continued supporting the work with material and in the long run more importantly, by seconding Tom Kilburn to work with me. The store was quickly developed to the state where one tube could store over one thousand digits (see Fig. 2).

The weakness of the c.r.t. store, in common with its chief rival, the delay line store, was its dependence on regeneration—it was a transient store that had to have its memory refreshed several times per second. Its strength lay in the fact that its component parts could be purchased 'off the shelf' and computers with storage capacities of from 12 kilodigits to as much as 340 kilodigits were in existence by 1948. It was regarded as an immediate access store despite the fact that reference could only be made to it at intervals of half a million nanoseconds.

Professor F. C. Williams graduated from Manchester University and Magdalen College, Oxford and was an assistant lecturer at Manchester University before the war. From 1939-1946 he worked on radar research at Bawdsey and TRE Malvern and on his return to Manchester he was appointed to the Chair of Electrical Engineering at the University which he still occupies. His pioneer contributions to electronic computer techniques have been recognized by numerous awards and medals from learned societies and institutions in this country and overseas.

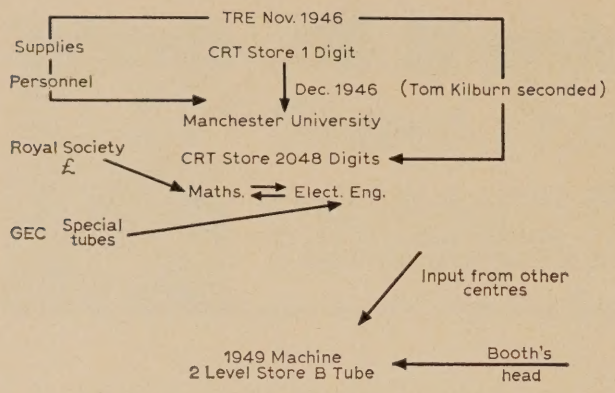

Fig. 1. The events leading up to the realization of the Manchester University 1949 computer.

With this store available, the next step was to build a computer around it. Tom Kilburn and I knew nothing about computers, but a lot about circuits. Professor Newman and Mr. A. M. Turing in the Mathematics Department knew a lot about computers and substantially nothing about electronics. They took us by the hand and explained how numbers could live in houses with addresses and how if they did they could be kept track of during a calculation. In addition, Professor Newman had a grant from the Royal Society. The collaboration was fruitful and by 1949 the state reached is shown in Fig. 3.

There is no need nowadays to elaborate on how the device worked or on the functions of its various parts but one or two features are worthy of comment.

It had a c.r.t. store with so-called immediate access of 5120 digits (not words) held on two cathode-ray tubes. This was backed up by a magnetic drum rotating synchronously with the scanning of the tubes and holding 40,960 digits. This store used Booth's head. It thus had multi-level storage which is still a feature of modern machines and it had it for the same reasons.

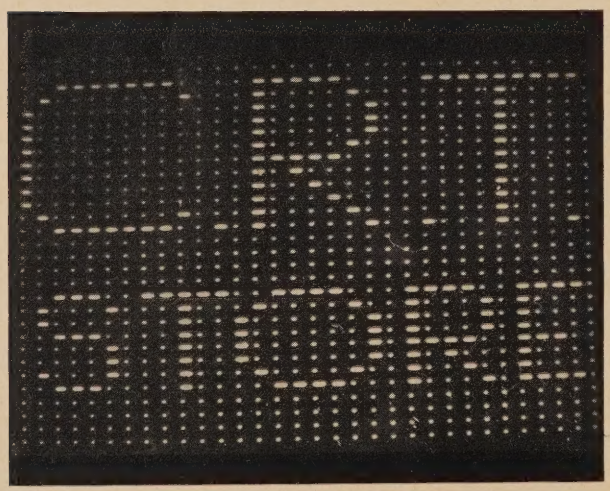

Fig. 2. Screen of cathode-ray tube store with 32 words of 29 digits.

It used two cathode-ray tubes A and C for the accumulator and control, and it had a third one which was called the B tube because the letters A and C had already been used up. This is the first known appearance of what is now called an index register or modifier and which is a valuable feature in modern machines. It was (and is) simply a means by which instructions drawn from the store can be modified before they are used. Since not all instructions must be so modified, each instruction carried within itself the seeds of its own destruction, called in our case the 'b' digit. If the digit was there, the instruction was modified, if not, it wasn't.

Finally the machine operated in the serial mode which lead to a conflict between mathematics and electronics. In mathematics the least significant digit occurs on the right. In serial machines the least significant digit must be operated on first in order that carries may be determined. It is well known in electronics that time flows from left to right, so the least significant digit must be on the left. The solution adopted was to employ a system of numbers called 'binary backwards'.

It is interesting to note that in several places this work is stated to have been carried out in the Royal Society Computer Laboratory at Manchester University. A find sounding phrase, but what was the reality? It was one room in a Victorian building whose architectural features are best described as 'late lavatorial'. The walls were of brown glazed brick and the door was labelled 'Magnetism Room'. What it looked like inside is shown in Fig. 4.

Since we are celebrating the 25th anniversary of stored program computers, we must examine whether this 1949 machine satisfied the definition of such a device. I know of only two definitions, one is my own and dates from my earliest contact with computing machines:

> 'A computing machine is a device for facilitating the performance of mathematics, the greater part of which would be very much better not done.'

Every time I get a bank statement this early view is reinforced. Our 1949 machine satisfied this criterion. The serious definition is to be found in Newman's contribution to the 1948 Royal Society discussion:[2]

> 'In opening the discussion Professor M. H. A. Newman said that it would be confined to machines which are *automatic*, i.e. require no human intervention at any stage; *digital*, i.e. such that separate digits of each number are stored in the machine at every stage (in contrast to "analogue" machines such as the differential analyser where the numbers are represented by directly measured physical quantities, e.g. lengths); and *general-purpose* machines, i.e. machines able without modification to carry out any of a wide variety of computing jobs.'

Regrettably our 1949 machine did not entirely meet this specification. It required human intervention during the solution of a problem.

The two-level storage I have referred to was indeed on two levels. The electronic store was in the magnetism room and the magnetic store in the room above. Transfers between the stores were achieved by setting switches,

then running to the bottom of the stairs and shouting 'We are ready to receive track 17 on tube 1'. The process was repeated for tube 2 and the machine set working. When the machine wished to disgorge information, it stopped and the reverse process was initiated.

In view of the trivial nature of this shortcoming and in view of the fact that it was soon removed, it may perhaps be excused.

In any case this was not the machine that had the greatest impact on computing at Manchester University. That honour must go to the machine that first operated in July 1948 as reported in a letter to *Nature* dated 3rd August 1948:[3]

'A small electronic computing machine has been operating successfully for some weeks in the Royal Society Computing Machine Laboratory, which is at present housed in the Electrical Engineering Department of the University of Manchester. . . .

. . .

'The development of this machine has been very actively supported by the Telecommunications Research Establishment, Great Malvern.'

This machine had a total storage capacity of 32 words each of 31 digits. These were contained on one cathode-ray tube. Two other tubes provided control and accumulator stores.

The total arithmetic unit was a subtractor located between store and accumulator which could:

(1) Write $-x$ into A

(2) Subtract x from A

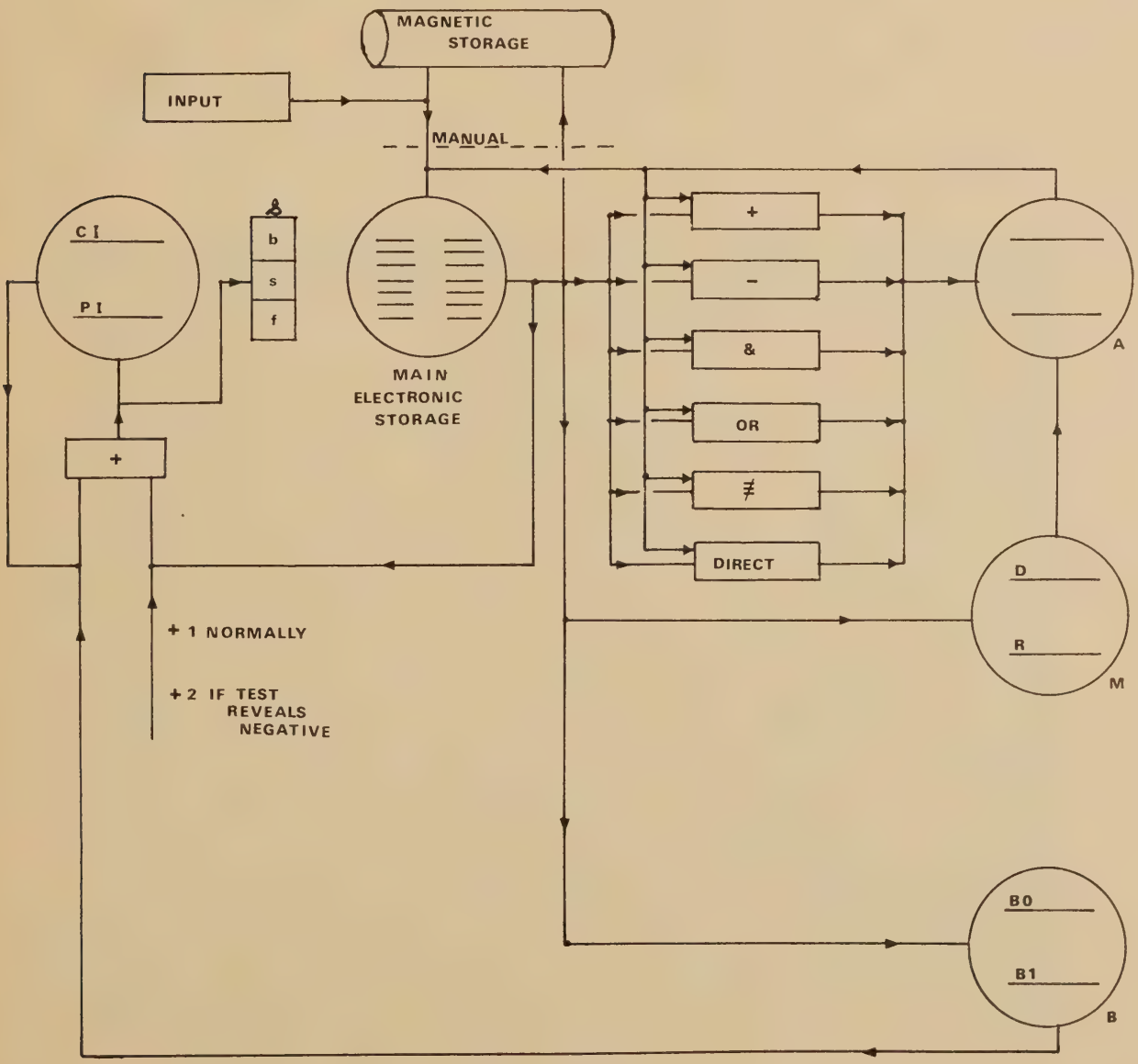

Fig. 3. The 1949 Manchester University machine. (From *Nature*, **164**, p. 684, 22nd October 1949.)

These two facilities permitted programming of all other arithmetic operations.

It could write from accumulator to store.

It had both unconditional and conditional transfer of control.

It could be instructed to stop.

Programs were inserted manually one digit at a time by setting in line and digit numbers on switch banks.

The machine was provided with a display tube similar to Fig. 2 showing the content of the store. Answers were read off from the appropriate line of this display.

When first built, a program was laboriously inserted and the start switch pressed. Immediately the spots on the display tube entered a mad dance.

In early trials it was a dance of death leading to no useful result, and what was even worse, without yielding any clue as to what was wrong. But one day it stopped and there, shining brightly in the expected place, was the expected answer, It was a moment to remember. This was in July 1948 and nothing was ever the same again. We knew that only time and effort were needed to make a machine of meaningful size. We doubled our effort immediately by taking on a second technician.

This machine solved a variety of problems including checking that 31 is the highest factor of $2^{30}-1$ by the clumsiest routine we could devise. This took 52 minutes during which 3·5 million operations were successfully performed.

Although in the mathematical sense this machine was 'so small it was no use at all', it answered Newman's 64-dollar question 'if they work at all' and it fully satisfied his definition. It required no human intervention during the solution of the problem and Newman had made a point of stating that mere lack of size was not a disqualification. For us, this was the breakthrough and sparks flew in all directions, see Fig. 5 where the small type is Fig. 1 reproduced. Professor Blackett saw it, and activated the Ministry of Supply. Within two months Ferranti Limited had an 'instruction to proceed', as below.

Copy of a letter from Sir Ben Lockspeiser dated 26th October 1948

Dear Mr. Grundy,

I saw Mr. Barton yesterday morning and told him of the arrangements I made with you at Manchester University. I have instructed him to get in touch with your firm and draft and issue a suitable contract to cover these arrangements. You may take

Fig. 4. The Royal Society Computing Machine Laboratory at the University of Manchester in 1949.

this letter as authority to proceed on the lines we discussed, namely, to construct an electronic calculating machine to the instructions of Professor F. C. Williams.

I am glad we were able to meet with Professor Williams as I believe that the making of electronic calculating machines will become a matter of great value and importance.

Please let me know if you meet with any difficulties.
Good wishes.

Yours sincerely,

B. LOCKSPEISER

E. Grundy Esq.,
Ferranti Ltd.,
Hollinwood, Lancs.

Two world records are claimed for this event:

(1) Speed of response by a civil servant.

(2) Brevity of specification.

Small as it was, this machine was big enough to make a Government Department move so fast as to commit £100,000 within two months to the construction of a machine the total specification being contained in the words 'to the instructions of Professor F. C. Williams'.

From then on events moved quickly to the Mark I machine inaugurated in 1951 upon which machine a nationwide computer service was based. The charge of £20 an hour seemed exorbitant at the time! Collaborative work with Ferranti continued and *Mercury* and *Atlas* followed, but this part of the story belongs to Tom Kilburn and leads to the formation of his now well-known Department of Computer Science, and which nowadays is somewhat larger than the Electrical Engineering Department from which it sprang.

My own interests drifted to other things like gas turbines. My investigations of these didn't set the world on fire, but they did set the Department on fire literally!

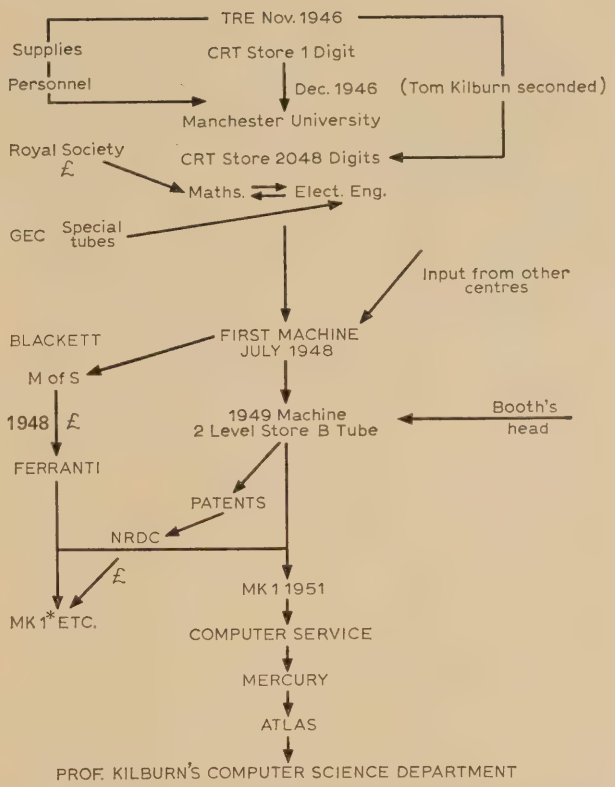

Fig. 5. The events leading up to the Manchester Mark 1 machines and the formation of the Department of Computer Science.

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Early computer developments at Cambridge: The EDSAC

Professor M. V. WILKES, M.A., Ph.D., F.R.S., C.Eng., F.I.E.E.

Presented at the Colloquium on the 25th Anniversary of the Stored Program Computer, held at the Royal Society, London, on 12th November 1974

Some time during the early summer of 1946 I received, quite unexpectedly, a telegram from Dean Pender of the Moore School of Electrical Engineering in the University of Pennsylvania inviting me to attend a course on the design of electronic computers. This was the famous course on which Presper Eckert and John Mauchly were the chief instructors. The opportunity was too good a one to miss.

I always think of the Moore School course as an outstanding example of the sharing of technological information, perhaps the most generous that has ever taken place. Eckert and Mauchly were fresh from their triumph as designers of the ENIAC and had been, along with Von Neumann and Goldstine, at the centre of the discussions that had taken place on the design of the EDVAC. The course was a landmark in my career and it was in Philadelphia, when it was finished, that I began to turn over in my mind the design of the machine that was afterwards known as the EDSAC. This, however, was by no means the beginning of my professional involvement in computing. When a student I had worked in the Cavendish Laboratory on the propagation of very long radio waves in the ionosphere and in March 1936, when I was beginning to write my thesis, I witnessed a demonstration of a working model of a mechanical differential analyser that had been constructed by J. B. Bratt on the initiative of Professor J. E. Lennard-Jones. I saw at once that this would be just the thing for solving a differential equation that was troubling me in connexion with the interpretation of my experimental results, and Lennard-Jones readily gave me permission to use it. This I successfully did.

Professor M. V. Wilkes is Professor of Computer Technology and Head of the Computer Laboratory in the University of Cambridge. He studied pure and applied mathematics at Cambridge University and did his doctoral thesis work at the Cavendish Laboratory in radio physics. During the war he was engaged in radar and operational research and, when the war was over, returned to Cambridge to take charge of the Mathematical Laboratory (now the Computer Laboratory). He was responsible for the construction of EDSAC 1, which was working early in May 1949.
With two colleagues, Professor Wilkes published, in 1951, the first book on computer programming and he is author of several other books. He has received numerous honours from universities and societies in Great Britain and abroad, and the British Computer Society, of which he was the first President (1957–1960), has made him a Distinguished Fellow.

Lennard-Jones was at that time steering through the University plans for the acquisition of a full-scale differential analyser and the establishment of a computing laboratory. He showed great vision in not viewing the acquisition of a differential analyser as an end in itself, but seeing rather the need for a permanent laboratory in which computing in all its aspects could be developed. The laboratory was established from the beginning of October 1937; Lennard-Jones was the part-time Director and I was the staff, with the rank of University Demonstrator. At the last moment it was decided to call it the Mathematical Laboratory, a name that served us well for over 30 years.

A new Anatomy School had just been built in Cambridge and the north wing of the old Anatomy School was assigned to the Mathematical Laboratory. Unfortunately, however, before the building could be rehabilitated and the laboratory formally opened, war came and I left Cambridge to work on radar and operational research. On my return in September 1945 I found myself, at first temporarily and then permanently, in charge, Lennard-Jones having decided to concentrate on his other interests. Thus, when I received the telegram and decided to accept the invitation to go to the Moore School, I did so realizing that, with luck, I might be in a position to take practical advantage of what I would learn. I had already heard from D. R. Hartree (then a professor in Manchester) and L. J. Comrie something of what was going on. Comrie had visited me in May 1946, just after he had returned from a trip to the United States. He put in my hand a copy of the famous EDVAC report that Von Neumann had drafted on behalf of the group at the Moore School and allowed me to keep it overnight. As there were no Xerox machines in those days, I could not take a copy of the report and so I sat up half the night reading it.

The EDSAC ultimately turned out to be about five times as large as I had envisaged when I first thought about it in Philadelphia. We were very unsophisticated in those days and I was young and innocent. Nowadays one would have to have a Project and Funding. I had sufficient money to get started and I trusted that somehow enough would come along to see me through. Mr. T. R. Thomson of J. Lyons and Company Ltd. heard about our work while on a tour of the United States. His company gave us much encouragement and a modest amount of financial help which, coming at the critical moment, kept us going. The D.S.I.R. also gave

us a little help and later we had earmarked money from the University Grants Committee. Lyons also seconded to us for well over a year E. H. Lennaerts, a member of their staff, whose services proved of great value. In return we helped them with the design of LEO 1 which, as far as the central processor was concerned, was a re-engineered version of the EDSAC. I was joined early in 1947 by W. Renwick who became the joint designer of the machine. S. Barton and G. Stevens joined in the same year and are still with us.

With my radio and radar experience I was entirely confident in ordinary circuit engineering. Entirely new problems, however, were posed by the requirement for a high-speed memory. It was quite clear to me from the beginning that this should be of the ultrasonic delay type. No such memory had been demonstrated up to that time, but, provided a satisfactory design for a delay unit could be arrived at, there was no reason to believe that the engineering of such a memory would be other than straightforward. Various proposals for memories of other types had been discussed in Philadelphia and I heard afterwards of the highly original work that F. C. Williams was engaged on; these, however, all seemed to involve a good deal of speculative research.

The type of delay unit contemplated was one in which ultrasonic pulses were transmitted along a column of mercury contained in a steel tube, quartz crystals being

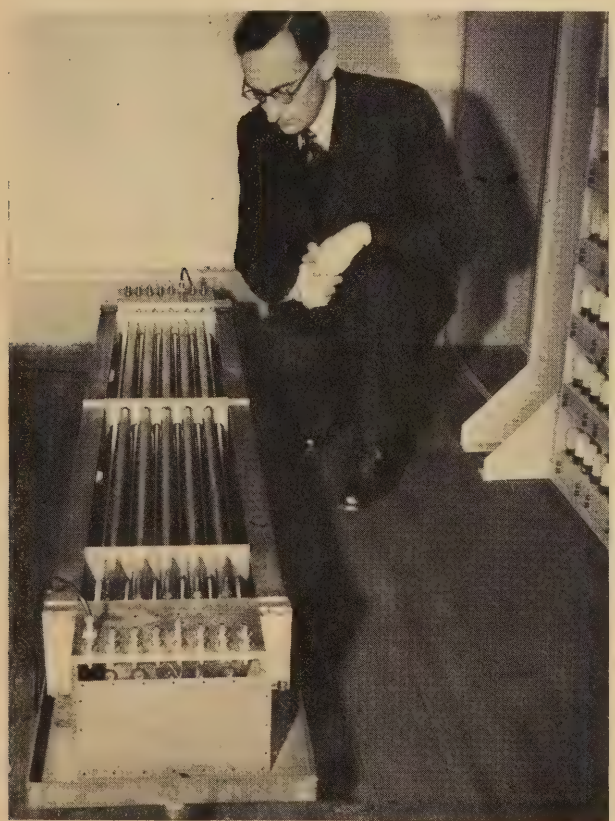


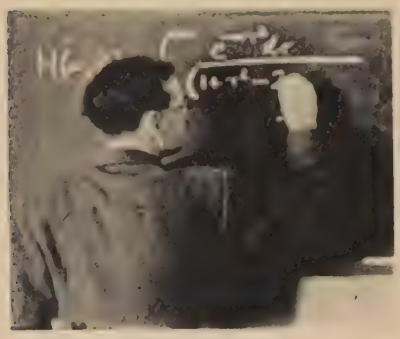
Fig. 1. Photograph taken in 1947 showing the author with one of the mercury tank batteries containing 32 ultrasonic delay lines.

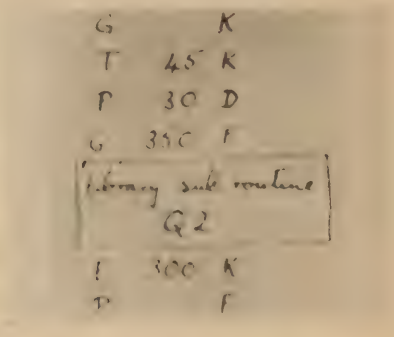
Fig. 2. General view of the EDSAC (1953).

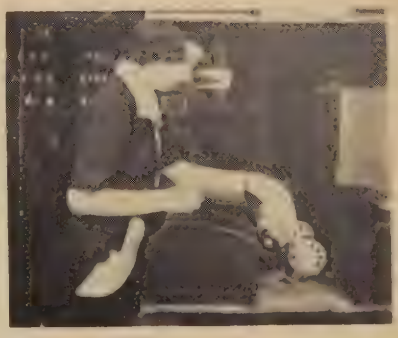
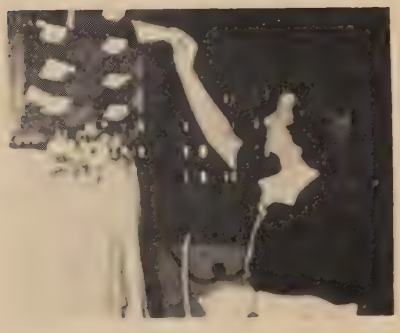
mounted at each end to act as electro-mechanical transducers. To avoid confusion with vacuum tubes, one spoke of *mercury tanks*. It was here that I had a stroke of very good fortune. I met T. Gold, who had returned to Cambridge as a research student after having worked in the Admiralty Signals Establishment during the war. While there, he had experimented with mercury tanks for the purpose of permanent echo cancellation in radar receivers. He was able to give me the essential parameters of a design which, he assured me, would work. I lost no time in having an experimental tank constructed and found that, indeed, it did work very well. For our purposes we needed not a single tank, but a good many, and I evolved a design for a battery containing 16 individual tanks (Fig. 1). I kept religiously to the dimensions that I had been given by Gold for the diameter of the tube, the active area of the quartz crystals, etc. The crystals at the two ends of each tube had to be aligned to within a few minutes of arc and this was achieved by accurate machining, there being no provision for adjustment. Two batteries were ultimately constructed for the EDSAC, giving 32 tanks in all. The same design was adopted for the LEO computer and also for a machine built by the Post Office for the Ministry of Supply.

In other respects, too, we were very conservative technically, since our object was to produce a machine that would work and not to exploit fully the technology that we had available. A crucial decision was to adopt a clock pulse frequency of 0·5 MHz, whereas any electronic engineer worth his salt regarded 1 MHz as a frequency that offered a reasonable challenge. It is to this attitude of conservatism, especially as regards the pulse repetition rate, that I attribute the fact that we were able to have a machine running by May 1949 (Fig. 2).

There were two things about computer engineering that made it different from the branches of electronic engineering that had gone before. One was the question of scale. In telephone repeater stations it was not unknown to have several thousand vacuum tubes operating in the same room; they were, however, grouped into independent channels and if one channel





Top Row
Stating the problem

Writing the program

A section of the program sheet

Second Row
Box containing library tape

Punching the program

Putting tape on queue

Third Row
Operator loading program tape

Photo-electric tape-reader

Operator taking results from printer

Bottom Row
Putting results into rack

Programmer examining results

Discussing results

went out of action the others could continue working. To have a system on that scale in which everything had to be working at once was something quite new that came with computers. In the EDSAC and other early stored program computers, although similar circuits were used repeatedly, there was little true modularity. I worked it out that, if the individual units were designed with the same care that television sets or radar sets were designed, construction of the machine would take over twenty years. One had to push ahead, cut corners, and above all, not try to get the most out of each vacuum tube. The other new thing about computer engineering was that the circuits had to be designed to handle transients correctly; in other words they could not be designed on the assumption that the waveforms were recurrent. It was a little time before I personally came to an explicit realization of this fact and to an understanding of its implications. I feared that other electronic engineers would also have to learn the hard way. In fact, when the time came, the know-how spread with surprising rapidity. We, along with other groups, had great trouble in making the mechanical peripherals meet our requirements for speed and reliability. The advances that were made in this direction, particularly as regards reliability, have been felt far outside the computer field.

As soon as the EDSAC began to work in May 1949, I called a meeting of programmers, and I remember saying that the initiative now lay in their hands. I can claim to be one of the people who discovered the existence of debugging. Somehow, at the Moore School and afterwards, one had always assumed that there would be no particular difficulty in getting programs right. I can remember the exact instant of time at which it dawned on me that a great part of my future life would be spent in finding mistakes in my own programs. In consequence of this realization the emphasis, even at a very early stage, was on developing methods of making programming a simple and reliable operation. The advantage of having a library of subroutines had always been clear, but it now took on an additional importance since library programs could be tested once for all. It was not long before D. J. Wheeler, then a graduate student, produced his famous idea for entering a subroutine from the main program and returning to it when the subroutine had done its work. The programming device by which he achieved this became known as the 'Wheeler jump'. We discussed a suitable name for the new kind of subroutine. Two suggestions were made, both, I think, by Wheeler himself. One was to call it a *reflexive subroutine* and the other to call it a *closed subroutine*. We chose the latter largely, I believe, because we liked the corresponding term *open subroutine*.

Anyone who reads our book 'The Preparation of Programs for an Electronic Digital Computer' published in 1951, but based closely on a laboratory report circulated in September 1950, may be surprised at the sophistication of the programming methods then in use. The EDSAC had a set of *initial orders* wired on to a mechanical read-only memory built with stepping switches (uniselectors) of the type used in telephone exchanges. When the start button was pressed, the initial orders were automatically copied into the high speed memory and it was under the control of these orders that the program tape was read. Instructions were punched in the form of a letter, indicating the function, followed by an address in decimal form and a terminating letter. We did not pass through the stage in which instructions were written in octal or hexadecimal notation. Originally the terminating letter was either an S or an L (for *short* and *long*) indicating that a half memory location or a full memory location was referred to. By October 1949, however, these initial orders had been replaced by a more elaborate set, devised like the first, by Wheeler, which provided load time relocation facilities for the components of which a program was composed, namely, a main program, subroutines, and blocks of constants and working space. To go with these initial orders I designed a routine, for which I coined the name *assembly routine*, that would assemble the components together and insert the necessary cross references. There were no multi-character identifiers, but otherwise the system provided in a primitive form the facilities provided by modern assembly routines. Also available were what would now be called software aids for debugging, including an interpretive trace routine written by S. Gill, also a graduate student.

It is possible to give a modern audience an idea of what computing was like in Cambridge in the 1950's by the fortunate circumstances that we still possess a film that we made at that time. It was, I believe, the first film of a stored program computer to be made; I showed it in London at the Royal Society of Arts in November 1951 and the following month in Philadelphia at the first Joint Computer Conference. Like all good amateur films this one tells a story. It opens with a scene in which a mathematician (played by A. S. Douglas) expounds to a group of experts a problem involving the evaluation of a definite interval. The group proceeds to discuss which library subroutines should be used. Subroutines are a recurring topic and in retrospect the film might be taken as a commercial for subroutines. Later scenes show the program being written, checked, punched, and finally run on the computer. By 1951 we had realized that it was advantageous, during the day shift at any rate, to have an operator to look after the machine instead of letting the programmers use it entirely by themselves. A feature of the ultrasonic memory was that it was possible to show on a c.r.t. raster the contents of one of the tanks and a scene in the film shows instructions entering the memory as they are read from the tape and converted to binary form. Finally, the programmer (played by S. Gill) collects the output from the rack in which it has been placed by the operator and proceeds to study it in company with the mathematician. A number of stills from the film are reproduced opposite.

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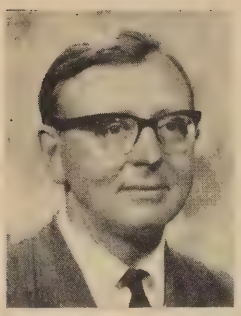

The Pilot ACE at the National Physical Laboratory

J. H. WILKINSON, Sc.D., F.R.S.

Presented at the Colloquium on the 25th Anniversary of the Stored Program Computer, held at the Royal Society, London, on 12th November 1974

Introduction

The ACE project at the National Physical Laboratory is of particular historical interest because of its connexion with the work of A. M. Turing. He and J. von Neumann are now universally acknowledged to be the two outstanding men of genius of the computer revolution, and it is a matter of some regret that we know so little of the exchanges which took place between them. However, this is not the place for a full appreciation of the contribution of Turing to computer science and I shall content myself with a brief account of my own association with the ACE project.

The Mathematics Division of the National Physical Laboratory was set up in 1945 in response to a need to coordinate the various scientific computing activities which had developed in an *ad hoc* way at a number of government establishments during the war. In addition to work in the general field of numerical mathematics its terms of reference specifically included research on new computing equipment. J. R. Womersley was appointed the first Superintendent and the Division included a desk computing section under E. T. Goodwin, a statistics section under E. C. Fieller, a punched-card section under T. B. Boss, a differential analyser section under J. G. L. Michel and an electronic computer section under A. M. Turing. Turing had been interested in automatic digital computing since the thirties when he had written his now world-famous paper 'On computable numbers, with an application to the Entscheidungsproblem'. His early research had been primarily of a theoretical nature but during the war his work at the Foreign Office had given him a knowledge of pulse techniques and it was this that led to an interest in the construction of an electronic computer.

Dr. J. H. Wilkinson received his mathematical education at Trinity College, Cambridge, and in 1946 became a member of the Mathematical Department of the National Physical Laboratory and worked with Dr. A. M. Turing, later going on to make an intensive study of electronic computers; his special interests are linear algebra and error computation. Dr. Wilkinson is currently a Special Merit Chief Scientific Officer at the NPL. In 1969 he was elected a Fellow of the Royal Society and the British Computer Society made him a 'Distinguished Fellow' in 1972; he has also received awards from American societies and in 1974 he was elected a Foreign Honorary Member of the American Academy of Arts and Sciences.

For the first few months at NPL Turing worked on this project entirely on his own, producing a comparatively detailed proposal[2] for the Executive Committee of the NPL, and this was duly accepted. Professor Williams has referred to the reckless doubling of staff which took place at Manchester University with the addition of a second man to the team. Turing proceeded with greater caution. I was recruited to NPL in May 1946 but was assigned to Turing for half time only; the other half was to be spent in the desk computing section acquiring a knowledge of numerical analysis.

When I arrived Turing was working on what he called Version V of his Automatic Computing Engine (ACE), the use of the word 'Engine' being in recognition of the pioneering work of Babbage on his Analytic Engine. ACE was to be a very large computer with a delay line storage of some 6400 words of 32 binary digits each, held in 200 long delay lines. Turing was confident that a megacycle pulse repetition rate would be perfectly practical and since each delay line stored 32 words the circulation time was 1024 μs, i.e. about one millisecond. The machine had a highly original code, though since at that time I had no other experience of digital computers this was not evident to me, and I only gradually appreciated how far out of step were projects elsewhere! Turing was obsessed with speed of operation; if consecutive instructions were to be stored in consecutive positions in a long delay line it would be possible to perform only one instruction per millisecond. To avoid this, consecutive instructions were stored in such relative positions that each emerged from a delay just as it was required in so far as this was possible. This subsequently came to be known as 'optimum coding' though Turing never used the expression; he thought of it just as coding. The use of optimum coding made it necessary to indicate in each instruction the storage position of the next. In order further to increase the speed of operation the computer was not based on the use of a central accumulator. Each instruction represented the transfer of information from a source to a destination. Included in the sources and destinations were, of course, the 200 long delay lines but there were also a number of short delay lines storing one or two words each and these were provided with functional sources and destinations. In addition to the natural arithmetic operations all versions of the ACE included a very full set of logical operations. Possibly because of his wartime experience Turing decided quite early on to use punched card equipment for input and output.

Early Programming Efforts

Later in 1946 M. Woodger joined the ACE Section, followed in 1947 by D. W. Davies and G. G. Alway and finally by Miss B. Curtis and J. H. Norton. Our task was to develop the logical design of the ACE in the light of experience gained in trying to program the basic procedures in mathematical computation. Version V was quickly abandoned and replaced by Versions VI and VII which were essentially four-address code machines in which each instruction was of the form

A FUNCTION B → C, NEXT INSTRUCTION D

This code was adopted partly in order to give a closer relationship between a mathematical algorithm and its coded version and partly to give greater speed; from Turing's point of view there is little doubt that the latter was the more important consideration. In some situations it virtually replaced three single-address instructions of the form

A → ACCUMULATOR; B → ACCUMULATOR, ADDING;
ACCUMULATOR → C

though this example much exaggerates its overall efficiency. The extra speed was attained at the cost of extra equipment; each delay line had to be fitted with two independent sources leading into two different highways; these highways led into a 'function box' from which emerged the required function of the two sources; the result was then fed directly to the required destination. An operation of the type A+B → C took only one word time; in Version VII this had become 40 μs (a minor cycle) since the word length had been increased to 40 binary digits to accommodate the more comprehensive instruction, though by that time we were more than willing to increase the word length for purely computational reasons. The maximum rate at which instructions could be executed was one every two minor cycles, one minor cycle being required for setting up the instruction and one for executing it. An intriguing feature is that the transfer of information from A and B to C could take place for a prolonged period of up to 32 minor cycles (the period of circulation of a long delay line), the period being determined by the position of the next instruction D. This made coding excessively untidy but in some situations it was a very powerful feature. One could for example, by means of an instruction

A+B → C continued for 32 minor cycles

add all 32 numbers in delay A to the corresponding numbers in delay line B and send the resulting sums to delay line C. By having the carry suppression at the end of every minor cycle, every other minor cycle, or omitting it altogether, one could deal automatically with single-word numbers, double-word numbers or multi-length numbers. In this way the fullest advantage was taken of the fact that ACE was a serial machine.

A great deal of quite detailed coding was done by the ACE team in the period from 1946–1948. It included basic subroutines for such things as multi-length arithmetic (including multiplication, division and square roots), floating-point arithmetic (both single-precision and double-precision) and interval arithmetic. The subroutines for floating-point arithmetic were particularly detailed; they were coded by G. G. Alway and myself in 1947 and were for both Version V and Version VII. They were almost certainly the earliest floating-point subroutines and it is interesting that those for the Version V were essentially the same as the subroutines which were subsequently used on the Pilot ACE itself. At a time when the arithmetic provided on modern computers is often so disappointing it is interesting to recall that the subroutines included provision for accumulating inner-products in double-precision floating-point arithmetic and all rounding was immaculate. During this period Turing introduced some of the earliest automatic coding procedures and he and M. Woodger did a fair amount of work in this area. The rather complicated nature of the code perhaps provided an inducement to develop such techniques though at the same time making it more difficult to do so.

A considerable effort was made on numerical linear algebra and some of this work is included in a Progress Report on the Automatic Computing Engine published in April 1948.[3] Solutions of linear systems by the Gauss-Siedel method and by Gaussian elimination with partial pivoting are included in this report. An interesting feature of these codes is that they make rather intensive use of subroutines; the addition of two vectors, multiplication of a vector by a scalar, inner-products, etc., are all coded in this way.

The Hardware Effort

The decision was taken quite early on not to set up a hardware section at NPL but to sub-contract this side of the work to some other government department, preferably where there had been previous experience with pulse techniques. Some decisions are seen to have been incorrect only in retrospect; this appeared to me to be a deplorable decision even at the time. Either the chosen department would prove not to be interested in the project in which case it would obviously be a bad decision or it *would* prove to be interested in which case NPL would inevitably have lost control of an exciting project. For the first year or so at NPL Turing continued his association with two of his former colleagues who were working in the Post Office Station at Dollis Hill but obviously this could not provide any sort of basis on which to embark on such an ambitious project.

In 1947 the policy of trying to get the computer built outside was finally abandoned and an Electronics Section was set up at NPL with responsibility to R. L. Smith-Rose, Superintendent of the Radio Division. The head of the Section was H. A. Thomas, an energetic man, but unfortunately his chief interest was in industrial electronics rather than in the construction of an electronic computer. The new Electronics Section was recruited mainly from members of other divisions of NPL who had some previous interest in electronics, but by and large they had to acquire expertise on pulse techniques by working on the project itself. However, two people, E. A. Newman and D. O. Clayden, were recruited from EMI and they certainly had previous experience that was wholly appropriate to the ACE project. Turing and

Thomas had virtually nothing in common and it was evident from the start that collaboration between the two men was unlikely to be satisfactory.

In January 1947 H. D. Huskey, on the advice of D. R. Hartree, came to the ACE section of Mathematics Division for a sabbatical year. Huskey had worked on the ENIAC and had considerable experience in the electronic field. Unfortunately his relationship with Turing was not particularly cordial though he cooperated extremely well with other members of the ACE section. He made no secret of his views that the idea of getting the computer built elsewhere was a mistaken policy and almost from the start pressed for a more active policy on the hardware side in Mathematics Division. Turing did not oppose this idea but never fully associated himself with it, possibly because he was becoming increasingly disillusioned with progress at NPL and had decided to take a Sabbatical at King's College, Cambridge, where he was still a Fellow. Huskey finally persuaded the rest of the group to work with him on the construction of a pilot machine which for simplicity was based on Version V. This machine was christened 'The Test Assembly'. The objective was to build the smallest computer which could successfully demonstrate the feasibility of Turing's grand project. I remember taking as our objective in the design the ability to solve a system of some eight simultaneous linear equations by the elimination method. Since it was not thought of as a permanent computer the full weight was thrown on the programmer and in deciding whether or not a feature should be included the question we asked ourselves was 'Could we possibly make do without it?'.

By the time the Test Assembly was under way Huskey was already half-way through his year at NPL. He was eager to have the computer working before he left and in retrospect this was clearly an impractical objective since he was mainly dependent on the members of the ACE Section of Mathematics Division for the design. Of these, only Davies had any real background experience and Alway, Woodger and myself were just learning 'on the job'. It is not surprising that this project was unwelcome to Thomas since its success would obviously have threatened his Electronics Section. Nevertheless, considerable progress was made with the construction of the Test Assembly before it was ruled that work on it should cease and the electronics side should be left entirely to Thomas's team. By this time morale in the Mathematics group was at its lowest ebb, with Huskey disillusioned and Turing away at Cambridge. For the next few months the group worked on the production of the Progress Report on the ACE. It is a pity that we did not decide to make it more comprehensive since many of the programs we had produced were the first in this field. Turing returned briefly to NPL in May 1948 but was so dissatisfied with progress that he decided to join F. C. Williams and T. Kilburn on the Manchester project.

The Pilot ACE

In 1948 Thomas decided to leave NPL for Unilever's, which was in line with his natural preference for industrial electronics, and F. M. Colebrook of Radio Division replaced him as head of the section. It was soon obvious to Colebrook that the ACE project was in a state of complete disarray and he came to the conclusion that the lack of communication between Mathematics Division and the Electronics Section was a severe handicap to progress. He had heard of the abortive Test Assembly project and was therefore aware that we were interested in the hardware side. Shortly after his appointment he came to see me and told me that it was his opinion that the enterprise was likely to founder unless something fairly decisive was done. He then made the remarkable proposal that the four of us who had been mainly concerned with the Test Assembly, Alway, Davies, Woodger and myself, should join his team temporarily and that we should all work together on the construction of some pilot machine. I was a little taken aback by the suggestion but on reflection decided that there was a lot to be said for it. It was clearly unsatisfactory to remain in Mathematics Division coding for a series of hypothetical machines and I was too fascinated by the idea of an automatic digital computer to contemplate giving it up and joining the desk-computer section. I was delighted to find that this view was shared by the other three. There remained the problem of squaring this with Womersley but fortunately I persuaded Goodwin (for whom in theory I was still working half-time!) to back the proposal and this virtually ensured its acceptance.

That Colebrook should make the suggestion, the four of us should be enthusiastic in our acceptance and that Mathematics Division should agree to our going was a remarkably improbable combination of events. There can be no doubt that it was an extremely successful experiment. The two groups were soon collaborating extremely well in spite of the previous unpromising experience. The comparative absence of friction owed a great deal to the tactful administration of F. M. Colebrook.

Early in 1949 we started on the detailed design of the Pilot Ace. In concept this owed more to the abortive Test Assembly than it was wise to emphasize. Again it was based essentially on Turing's Version V and the equipment was kept as simple as possible consistent with the objective of being able to carry out significant computations. The original design included no multiplier since optimum coding made it possible to perform a programmed multiplication in about 10 milliseconds. A very compact form of construction was decided upon, with interchangeable plug-in chassis. The logical design could be taken over without substantial modification from Version V and the earlier Test Assembly; the circuit design was undertaken by members of both groups.

By the Autumn of 1949 the completed chassis were being delivered from the NPL workshops and the assembly was under way. Initially the assembly was done by G. G. Alway and myself but quite soon E. A. Newman joined us and the three of us then worked together until the computer was in operation. The first half of the machine was assembled very rapidly but in December 1949 the main control chassis were added

and progress became slower. By February 1950 sufficient number of chassis had been added for it to be capable of storing and carrying out a simple program but it was not until May that it actually did so. In 1950 E. C. Bullard had succeeded Sir Charles Darwin as Director of NPL and on his tour of inspection of the Laboratory he paid us a visit. He had obviously heard of the earlier trouble with the ACE project and was a little sceptical when we said that we would have something working 'almost any day'. We promised to let him know when we had and it was fortunate that this occurred about a week later.

Towards the end of the day on 10th May 1950 we had all the basic pulse circuits working, the control unit, one long delay line and a short delay line fitted with an additive and subtractive input. However, our only method of inserting instructions was via a set of 32 switches on which we could set up one instruction at a time in binary; our only method of output was a set of 32 lights to which a binary number could be sent. Unfortunately the amplifier on the delay line was barely adequate and the probability of remembering a pulse pattern for as long as a minute was not very high. We concocted a very elementary program consisting of a few instructions only; this took the number on the input switches, added it into the short delay line once per millisecond and put on the next light on the set of 32 output lights when the accumulator overflowed. The lights therefore came on at a speed which depended on the size of the number on the input switches. We laboriously fed this program again and again into the computer but each time the memory would fail before we could finish. On about the twentieth occasion we finally succeeded in inserting the whole program and all the lights flashed up instantaneously. We reduced the input number and they came on slowly one by one; we doubled it and the lights came on at twice the rate and we switched off for the day knowing the computer was working. It was another two days before we again reached this high peak and could convince the Director that it *was* working.

From that point onward we were under constant pressure to have a demonstration for the Press, but there was a good deal to do before this was possible and eventually we fixed on a December date. Most early computer builders have a 'hard luck story' for their first demonstration day. Ours was a good luck story. For the demonstration we had three main programs, two popular and one serious. Of the popular programs the first took a date in decimal from input keys and gave out the corresponding day of the week on a cathode-ray tube while the second took a six-figure decimal number and gave its highest factor. A bottle of beer was offered to any member of the Press who could give a six-figure prime. Popular programs provide a merciless test since the slightest error is readily apparent. The serious program traced the path of rays through a complex set of lens; it was virtually impossible for anybody not intimately connected with the computer to know for certain whether this was working correctly. Up to within a few days of the demonstration period the computer had never performed the serious program correctly and we were not even certain that the program was free of errors. In the event the Pilot ACE worked virtually perfectly for the whole of the demonstration period, a level of performance which was not achieved again for some considerable time.

The Pilot ACE and DEUCE

The Pilot ACE had been designed purely as an experimental machine with the object of demonstrating the competence of the team as computer engineers. It was originally intended that when it was successfully completed a full-scale computer would be built. In the event it did not work out like this. At the time when it was successfully demonstrated it was the only electronic computer in a government department and indeed the only other working computers were EDSAC at Cambridge, SEAC at the National Bureau of Standards and an early version of the Manchester machine. We naturally came under very heavy pressure to use the Pilot ACE for serious computing. We accordingly embarked on a small set of modifications which included the addition of an automatic multiplier and improvements to the control unit which made programing a little less arduous. The computer was then put into general use and did yeoman service for a number of years.

Initially its only storage consisted of mercury delay lines which altogether held some 300 words of 32 binary digits each. This had to cover both instructions and numbers and the code was, of course, fairly inefficient in terms of storage space required for a given program. However, for a number of reasons the Pilot ACE proved to be a far more powerful computer than we initially expected. Oddly enough much of its effectiveness sprang from what initially appeared to be weaknesses resulting from the economy in equipment which dictated its design.

Optimum coding was a controversial matter at the time but much of what was said about it appears in retrospect to have been irrelevant. Of course nobody would use optimum coding if the same effect could be produced without it. However, faced with the same choice as we had then I would certainly use it. An illustration of its effectiveness is provided by the floating-point routines on Pilot ACE. Programmed floating-point arithmetic involved a considerable number of instructions and on a conventional computer such as EDSAC, which performed only one instruction per circulation time of a long delay line, it was too slow to be used for any extensive computation. On Pilot ACE it was only marginally slower than fixed point arithmetic thanks to optimum coding. The speed was further increased by the elementary nature of the multiplier. This was an entirely autonomous unit which did not even deal with signed numbers. However, both the sign correction and the manipulations of the exponents could be carried out while the multiplication was proceeding and hence this effectively took no extra time. Even double precision and triple precision floating-point routines were reasonably fast and we gained extensive

experience with such computation long before it was much used elsewhere. I think it is not unreasonable to claim that the development of floating-point error analysis at NPL, which was well in advance of that elsewhere, was an indirect consequence of our use of optimum coding.

Again the very elementary way in which input and output from punched cards was organized played a decisive role in their use. A great deal of numerical linear algebra with matrices of comparatively high order was done on the Pilot ACE using storage in binary on cards. The multiplication of a vector held in the store by a matrix stored on cards was performed by reading the cards at full speed through the reader, all the computation and red tape being done in the intervals between rows of cards. This was faster than would have been possible on EDSAC or SEAC even if they had had adequate high-speed store. By putting two numbers on each row of a card we could have doubled this speed.

Since this use of the punched card equipment required the use of an operator, it indirectly encouraged user-participation generally and this was a distinctive feature of Pilot ACE operation. Speaking for myself, I gained a great deal of numerical experience from user-participation and it was this that led to my development of backward error analysis. Present day developments are again moving in this direction but they do not yet provide as satisfactory participation as we took for granted on the Pilot ACE. It is difficult to imagine greater differences in the philosophies of computer usage than between those which developed at Cambridge on EDSAC and NPL on the Pilot ACE. I have often wondered whether it was the machines which determined the development or whether it was the natural characteristics of the personnel involved which led to the development of such different computers.

During the period when the Pilot ACE was being built the English Electric Company became interested in electronic computers and a small group from the company joined us at NPL, though all the construction was done in NPL workshops. After the success of the pilot machine English Electric decided to gain experience by building engineered versions of this computer. I was not in favour of this decision since it perpetuated something that had originally been designed merely for experimental purposes and it removed any sense of urgency from the development of the full scale ACE. However, before these engineered versions were produced a magnetic drum store was added to the Pilot ACE and with this addition it was, in spite of its obvious shortcomings, a very powerful computer. In the event the engineered version, marketed under the name DEUCE, was undoubtedly a success, as will be described by A. C. D. Haley later in this Symposium.

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Computers in the University of London, 1945-1962

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Presented at the Colloquium on the 25th Anniversary of the Stored Program Computer, held at the Royal Society, London, on 12th November 1974

My own work in the field of computation started during the early 1940s when I was concerned with the determination of crystal structures using X-ray diffraction data.[1] In the computation of electron density maps for structure analysis, very heavy calculations are involved on large quantities of numerical data, and the state of the art in the early 1940s was such that the limits of human ability in this area were reached at structures containing not more than about 10 crystallographically distinct atoms. The formal mathematical problems involved are displayed in the following formulae:

$$\rho(x, y, z) = \frac{1}{V} \sum_{-H}^{+H} \sum_{-K}^{+K} \sum_{-L}^{+L} |F(hkl)_0| \times \cos\left[2\pi\left(h\frac{x}{a} + k\frac{y}{b} + l\frac{z}{c}\right) - \alpha_{hkl}\right]$$

$$F(h, k, l) = \sum_{r=1}^{N} f_r \cos\left[2\pi\left(h\frac{x_r}{a} + k\frac{y_r}{b} + l\frac{z_r}{c}\right) - \alpha_{hkl}\right]$$

$$\tan \alpha_{hkl} = \frac{\sum_{r=1}^{N} f_r \sin 2\pi\left(h\frac{x_r}{a} + k\frac{y_r}{b} + l\frac{z_r}{c}\right)}{\sum_{r=1}^{N} f_r \cos 2\pi\left(h\frac{x_r}{a} + k\frac{y_r}{b} + l\frac{z_r}{c}\right)}$$

The first gives the electron density $\rho(x, y, z)$ in terms of the observed structure factors $F(hkl)_0$ and the positional co-ordinates (x, y, z). The second enables these structure factors to be calculated when approximate positions of the atoms are known, and the third determines the phase angles α_{hkl}. Iterating with a combination of the results of these formulae, it is usually possible to obtain a precise definition of atomic co-ordinates. The determination of a ten atom-type structure involved, in the early 1940s, about six weeks of experimental work followed by anything up to three years of hand computation for a group of human 'slaves' and, even during wartime, I was trying to design equipment to mechanize parts of the crystallographic process. The results of one of these attempts[2] is shown in Fig. 1 which represents a small digital machine for the evaluation of structure factors. At the conclusion of hostilities, I moved for a short time to the British Rubber Producers' Research Association at Welwyn Garden City which was under the inspired Directorship of Mr. John Wilson, M.C., C.B.E. John Wilson has been a friend ever since and was enthusiastic for my project to build automatic machinery for mechanizing the whole process of X-ray structure determination. He provided funds for a succession of projects, the first of which was for a completely automatic but mechanical method[3] for calculating the structure factors just mentioned. The complex equipment was built, and an example of one unit is shown in Fig. 2.

At this point in time, however, I became interested in the possibilities of digital computation, and again received the support of John Wilson, even though I had by this time transferred my allegiance to Birkbeck College in the Physics Department under the late Desmond Bernal. With the help and encouragement of these farsighted scientists, I started on the construction of a relay calculator for the automatic computation of all of the elements required in X-ray crystal structure analysis. This work was accomplished during the period of 1945 to early 1946. Our work on the relay structure factor calculator was nearly complete at the end of 1945. Its circuit included what would now be called a many-one and a one-many function table for decoding and executing instructions. This particular device was invented by me without any knowledge of work which was going on elsewhere but before its final completion, the publicity which the machine attracted led the late D. R. Hartree to visit my laboratory, and it was from him that I learned of the exciting developments which were going on in the field of electronic computation in the United States.

Desmond Bernal was also intrigued by this work and, as a result of his efforts, he secured funds for me to visit the United States under the auspices of the Rockefeller Foundation. During this visit, I looked at the work of a number of groups including that of Von Neumann

Dr. A. D. Booth (Fellow 1956) first became involved with computers in the war years and he was a pioneer in the use of magnetic storage techniques. During the fifties he held successively the positions of Director of the Birkbeck College Computer Project, University Reader in Computation Methods and Head of the Department of Numerical Automation at Birkbeck. In addition to having been Chairman of the IERE's Programme and Papers Committee, Dr. Booth was first Chairman of the Computer Group Committee. He is currently President and Vice Chancellor of Lakefield University, Thunder Bay, Ontario; from 1963 to 1972 he was Dean of the College of Engineering at the University of Saskatchewan.

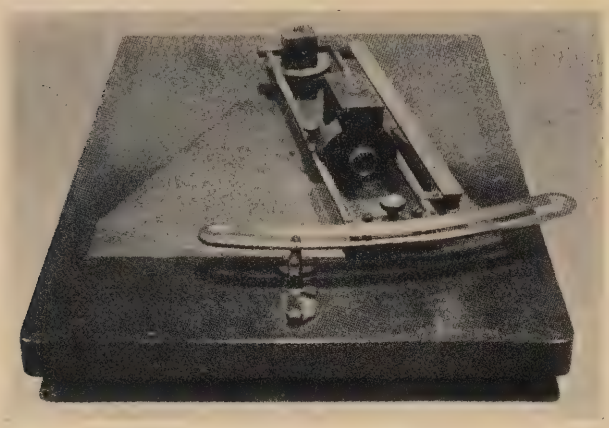

Fig. 1. Digital structure factor calculator.

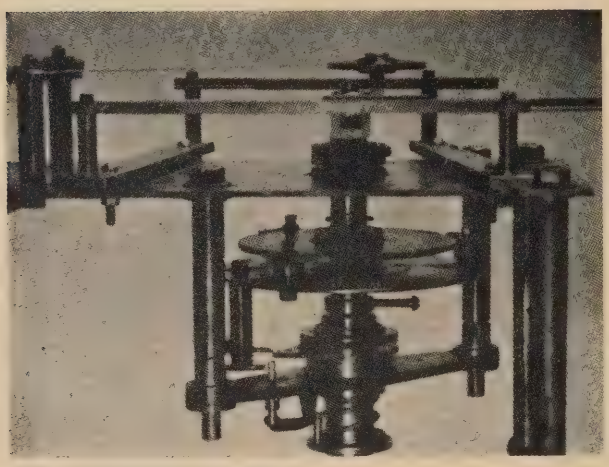

Fig. 2. Unit of automatic analogue computer.

and Goldstine at Princeton, J. W. Forrester at M.I.T., and Howard Aiken at Harvard. At the conclusion of the visit, the Rockefeller Foundation offered me a Fellowship to work at an institution of my choice in the United States and in the field which I have mentioned. My choice fell immediately on the Von Neumann group at the Institute for Advanced Study at Princeton, not because I had seen anything of the hardware of their project, which I had not, but because the rigorous logic and precise thought of Von Neumann attracted me: it had none of the airy imprecision of some of the other workers.

On my return to the United Kingdom, work on the X-ray calculator was suspended, and my research assistant, Miss Kathleen Britten (now Professor Kathleen Booth) and I devoted ourselves to exploring the joys of logical design on the Von Neumann principle. This design was directed entirely at serial operation and was really an exercise in mathematical enjoyment rather than anything of a practical nature. It was, however, at this same period (late 1946) that I became seriously interested in the problems of large-scale storage and conducted an analysis of the physical phenomena which might be used for storing information. The results of my analysis, later confirmed and refined during my stay at Princeton, led to a rejection of the mercury delay line, which was then well known, and practically all of the transient phenomena such as secondary emission storage and charge storage on discrete capacitors. I identified magnetic processes as the only ones which, in my opinion, had any potential for large-scale long-term storage. I also sketched out various embodiments of the magnetic principle, ranging from disks to drums, but took no steps to construct any of them.

During my stay at Princeton (March–September, 1947), I developed an even greater appreciation of the virtues of Von Neumann and of his mode of thought. I concluded that the electronic technology at Princeton was so far ahead of that available to me at that time, and that the equipment involved was so costly that there was no hope of my producing a fully electronic machine in a short time, neither for that matter was there any hope of acquiring the 'Selectron' tube which was to be the storage organ of the original Princeton machine. Miss Britten and myself divided our efforts. I designed a 21-bit parallel binary arithmetic and control unit using Siemens high-speed relays whilst at the same time she developed programs for this device, one of which is shown in Fig. 3. Having designed the relay machine, Kathleen Britten tested some of the circuits for me, and I went on to investigate the ways in which I could build

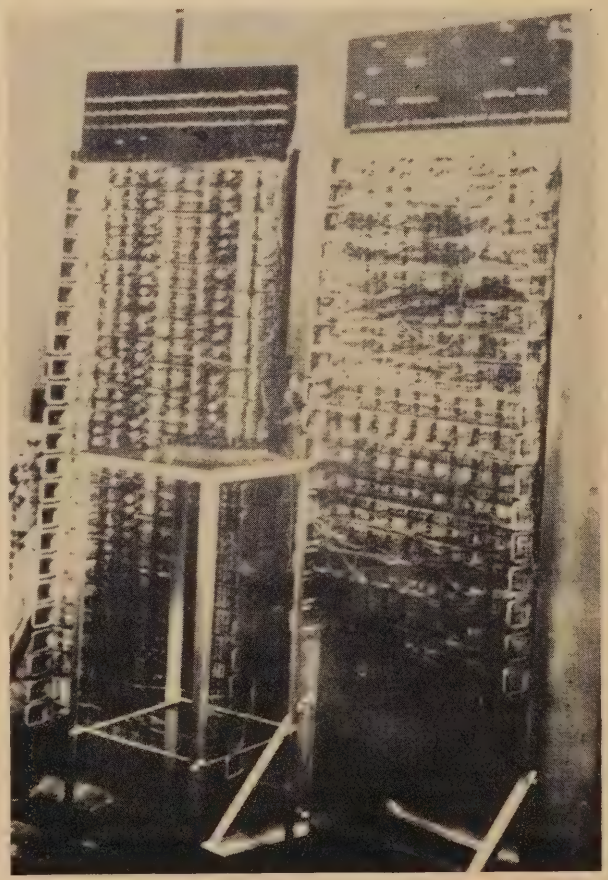

Fig. 4. Relay arithmetic and control unit of A.R.C. (1947) (now in Science Museum, London).

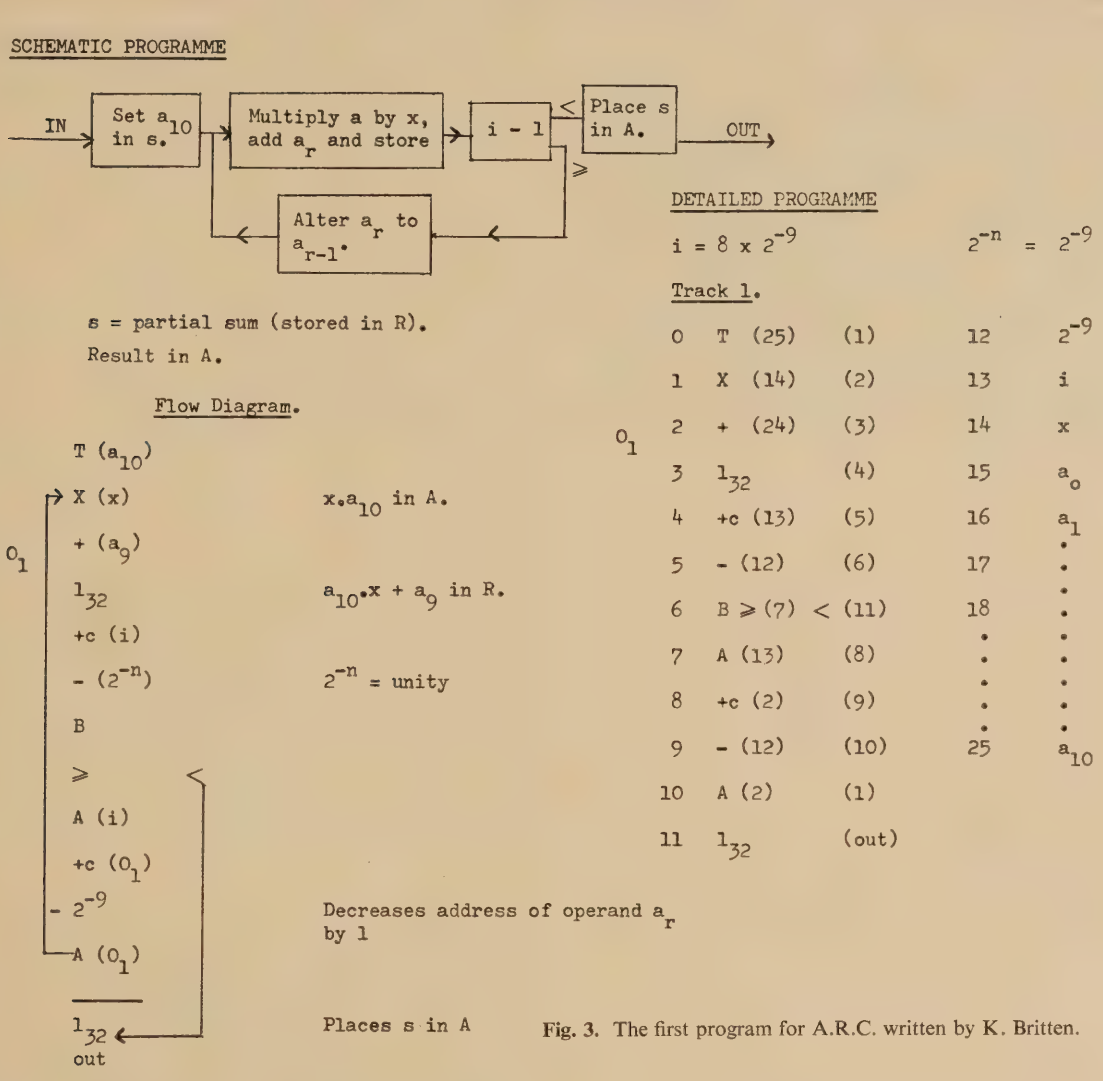

Fig. 3. The first program for A.R.C. written by K. Britten.

a magnetic storage organ and completed both the electronic and the mechanical design for such a system by May or June of 1947.

On our return to the United Kingdom, and using the facilities of the British Rubber Producers' Research Association since no laboratories were available at Birkbeck College, we started on the construction of our machine. My first experiments on magnetics involved the use of a thin oxide-coated paper disk extracted from a 'Mail-a-Voice' recording machine. The notion was that, under centrifugal force, the disk would remain approximately flat and that the Bernoulli effect forces would keep it in close proximity to a reading and recording head. However, experiments revealed gross instabilities, and having neither time nor resources to work upon the elimination of these, I turned to a second alternative which was the magnetic drum. A simple drum was constructed and nickel-plated. An important feature of the system was that we used a pre-recorded clock track and a counter and coincidence sensing system to identify position on the drum.

I worked on this system and completed an input–output device for use with the drum.[4] This system was attached to the relay arithmetic unit which, by this time, was operational and so the A.R.C. was born. Some extracts from my 1947–48 diaries are shown in Table 1, and I draw attention to two which are of significance—the first, Wednesday, 18th February 1948, where Mr. D. M. Livsey, a Patent Agent, was consulted with reference to the A.R.C. machine. The information supplied to him included a description of the magnetic disk store and the drum equivalent thereof. The A.R.C. machine was operational by 12th May and was demonstrated to Sir William Palmer, the then Chairman of the Board of the British Rubber Producers' Research Association. Just a few days later, we also gave a demonstration to Warren Weaver and Gerard Pomerat of the Rockefeller Foundation who were visiting the United Kingdom at that time. The A.R.C. system and the store are illustrated in Figs. 4 and 5.

Our staff at that time consisted of two people—myself working on the electronic side of the machine, and Miss Britten working on programming and generally maintaining the relay circuits.

With A.R.C. completed, I turned my attention to the development of a fully electronic version of the machine,

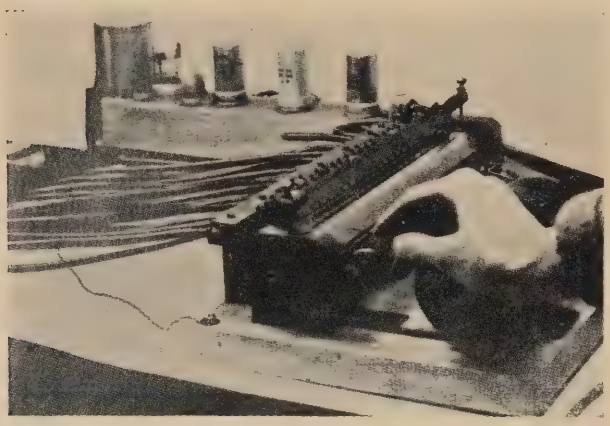

Fig. 5. The first working, full-scale, drum store. Used on A.R.C. and SEC (now in Science Museum, London) (1947).

SEC, and for reasons of simplicity, adopted the serial mode using shift register techniques. This was something which no other project, as far as I know, had attempted. The Wilkes machine, and its prototype EDVAC, used mercury delay lines as shift registers. My charge-storage type shift register proved to be the prototype of most of the shift registers developed and used in the future, and the basic design is still in general use.

The A.R.C. machine worked in the one address mode, but we soon realized when we came to construct SEC that the magnetic drum, with its mean random access time of 1/100th of a second could be much speeded up operationally by the adoption of a two-address code and in fact, as shown in our book[5] the design of a two-address machine using shift register techniques is actually simpler than that of a single-address machine using a control counter. The SEC was completed with the assistance of a research student, Mr. N. Kitz.

The electronic hardships which we suffered were considerable. The only valve which was available to us was the VR102, a revolting version of the 6SN7 double triode in which one of the grids was brought out to a top cap with consequent clumsiness of the associated wiring. With the assistance of the Rockefeller Foundation, however, I was able to acquire a large stock of 6J6 valves and, with these, we constructed the first of the APEXC series of machines (Fig. 6), the research student involved in this project being Dr. B. Zacharov who has since had a distinguished career both in computing and in instrument design. A number of APEXC machines were built, amongst them one for Birkbeck College, one for the British Rubber Producers' and one for the British Rayon Research Association to which Mr. J. Wilson had, by that time, moved as Director of Research.

The late John Womersley, one of the original ACE pioneers, had moved from National Physical Laboratory to the British Tabulating Machine Company by this time, and knowing of our project, approached me with a proposition that we join forces and that the British Tabulating Machine Company undertake the manufacture of our machines. This they did, the resulting series being named HEC.

Table 1. Extracts from 1947–48 diaries

1947	
Tuesday, March 18th	'Considering possibility of new memory organ'
Wednesday, March 19th	'. . . Wire and paper memory'
Thursday, October 23rd	'. . . Shifting register working'
Wednesday, November 12th	'. . . Coincidence circuit complete and working'
Saturday, November 22nd	'Worked on pole piece design'
Tuesday, December 16th	'. . . Full accumulator working'
1948	
Thursday, January 1st	'Got memory working'
Monday, January 5th	'Saw F. C. Williams' [at Manchester]
Wednesday, February 18th	'O'Donnel Livsey . . . *re* patents in A.R.C.'
Thursday, February 19th	'256 pulses on!' [i.e. 256 words of drum storage (2″ dia. nickel plated drum)]
Wednesday, May 12th	'. . . . Work on m/c—debugged completely. Sir William Palmer, Mr. Dickie [& others] came to see m/c—impressed'
Sunday, May 23rd	'Met Weaver and Pomerat. To W.G.C. showed m/c'

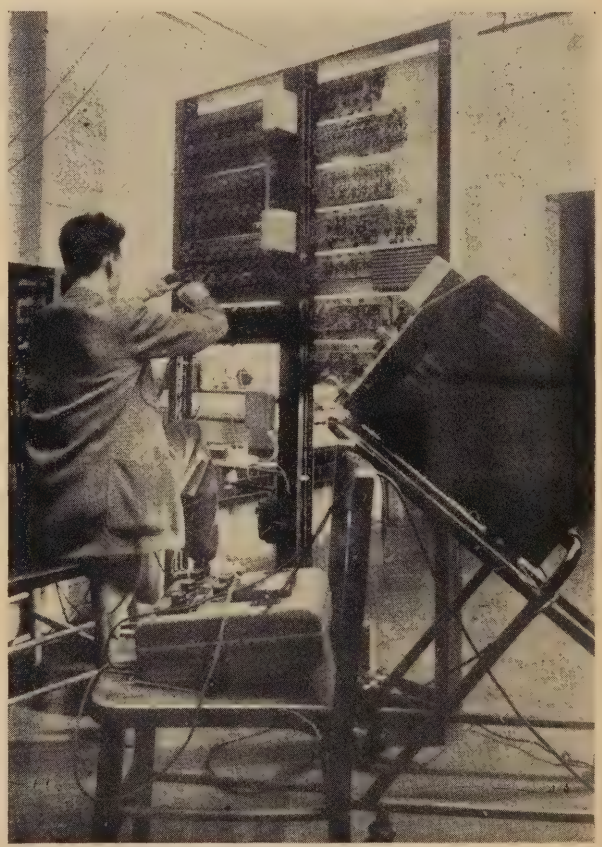

Fig. 6. APEXC (B. Zacharov) 1951.

Fig. 7. MAC.

The Birkbeck group continued in existence until 1962 when I left the country. We produced a large number of machines. From APEXC we developed the machine called MAC, shown in Fig. 7, and later a more sophisticated and stylish version which was called M2. These were all hot valve machines and employed semiconductors only in the function table for which we used selenium disks which cost only a fraction of a penny—all we could afford at the time. In M2, a very few point-contact semiconductor diodes were used in appropriate places. A number of M2 machines were made, and I used this machine as a means of supporting my research students and laboratory during the latter part of my sojourn at Birkbeck College. A number of my students worked on these projects, and their names deserve a place in the history of computers—John Cleave, now at the University of Bristol, who did pioneer work in the field of machine translation; Michael Levison, who worked on machine linguistics and is now at Queen's University, Kingston, Ontario, Canada; Martin Prutton, who has left the computer field, but is an authority on semiconductors; and Andrew Colin, who became, in due course, Director of one of the University Computing Laboratories.

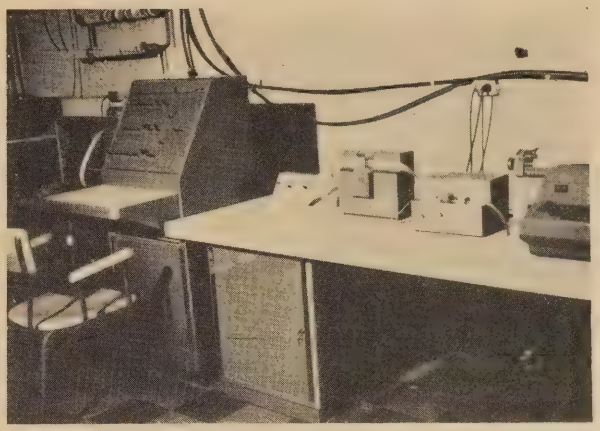

Fig. 8. M3 (University of Saskatchewan) 1963.

My history is now more or less complete and I will only remark that, on coming to Canada with its North American expertise, we rapidly constructed a totally semiconductor version of the M2. This was called M3 and shown in Fig. 8. The architect of victory for this machine was Mr. Ken Cameron who built the machine and debugged it in a period of ten months for his Master's Degree. M3 is still working in Saskatchewan as is one of the M2 series donated to the Moose Jaw Technical Institute. The M2 has been extended in a number of directions and has worked for well over ten years without serious malfunction or any real servicing. I believe that this is probably the only machine directly descended from the original which is still operational, and I believe it significant that my original design has proved capable of receiving, without adaptation, multiple inputs, analogue-digital converters, and even a core store.

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The effect of the polarization characteristics of the receiving feed on cross-polarization of receiving reflector antennas

S. I. GHOBRIAL, B.Sc., M.Sc., Ph.D. *(Graduate)**

SUMMARY

A method for calculating the co-polar and cross-polar radiation patterns of reflector antennas when operated in the receive mode is discussed. A formula for cross-polarization isolation is derived. Methods for cross-polarization reduction are discussed in the light of the obtained results. Numerical computations resulted in excellent agreement between the present method and previously used methods. Practical measurements also confirm the validity of the derived formulae and the conclusions drawn.

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1 Introduction

The growing interest in frequency re-use systems employing orthogonal polarizations stimulated many authors to consider the problem of cross-polarization in reflector antennas and seek techniques for its reduction.[1–8] Since reflector antennas comprise a primary feed and a reflecting surface it is therefore natural to ask the question, which of these is more responsible for cross-polarization? The answer to this question elucidates methods of improvement of the polarization performance of these systems.

The common technique for calculating the cross-polarization performance of an antenna is the current distribution method. In this method one obtains the polarization of the field after reflexion by applying the boundary conditions at the reflecting surface to the incident field from the primary feed. The far field is then obtained by integrating each field component over the reflecting surface. Now the field due to most common primary feeds is not free from cross-polarization. In addition the curved reflecting surface depolarizes the incident electric vector and further cross-polarization results. It is thus difficult to see the roles played by reflector and primary feed. A new approach that allows one to see the effect of reflector and primary on the total cross-polarization of the system is therefore needed. In the present work a new method for calculating the co-polar and cross-polar radiation patterns of reflector antennas when operated in the receive mode will be discussed. The derived equations have the advantage of being expressed in terms of the polarization characteristics of primary feed and reflecting surface. This allows close investigation of the effect of each. A formula for cross-polar isolation will also be given and methods of cross-polarization reduction will be discussed in the light of derived equations.

2 Analysis

2.1 Feed Polarization Consideration

Consider a feed (which could be a horn or a dipole) placed at the focus of a reflector (we will consider the general case of any reflector or combination of reflectors, e.g. front-fed paraboloid, Cassegrain, etc.) which is excited by a plane wave. Our objective is to determine the voltage that appears at the output terminals of the feed. In order to achieve this, let us start from the plane incident wave and let us assume that the incident wave is linearly polarized. On reflexion the wave is depolarized and the components of the reflected **E** vector along the x, y and z axes can be obtained from the reflecting matrix[1] of the reflecting system. Let the reflected **E** vector be denoted by $\mathbf{E}_r$. Now let us consider the feed in the transmit mode. If the far field of the feed when transmitting be denoted by $\mathbf{E}_f$, then using the Lorentz reciprocity theorem[8] the voltage appearing at the terminals of the feed can be written as:

$$V = c \iint_S \mathbf{E}_r . \mathbf{E}_f \, e^{-j\delta} \mathbf{r} . d\mathbf{S} \qquad (1)$$

where c is a constant,

$\mathbf{r}$ is a unit vector along the ray from the element $d\mathbf{S}$ to the focus,

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δ is the sum of the phase angles associated with $\mathbf{E}_r$ and $\mathbf{E}_f$ at dS, being a function of the off-axis angles.

In equation (1) all quantities are independent of the off-axis angles except δ and $\mathbf{E}_r$. It can be easily shown that the change in the components of $\mathbf{E}_r$ with off-axis angles is negligible. It follows that the radiation pattern of an antenna may be computed from (1) by evaluating the integrals for different off-axis angles and therefore different δ.

2.2 Co-polar and Cross-polar Voltage Calculations

In the above analysis no distinction was made between matched polarization and cross-polarization. Equation (1) gives the voltage measured at the feed terminals independent of whether the feed is oriented to receive the matched polarization or otherwise. To distinguish between the two cases (i.e. matched and cross-polarized) let us assume that the incident wave is polarized along the x-axis, thus

$$\mathbf{E}_r^x = \mathbf{i}E_{rx}^x + \mathbf{j}E_{ry}^x + \mathbf{k}E_{rz}^x \tag{2}$$

where the superscript x denotes the polarization of the wave prior to reflexion.

Now if the feed is oriented in such a way that when radiating produces (in the direction of maximum power flow) a wave that is polarized along the x-axis, then we say that the feed is oriented to receive the matched polarization. Let $\mathbf{E}_f$ be written as:

$$\mathbf{E}_f^x = \mathbf{i}E_{fx}^x + \mathbf{j}E_{fy}^x + \mathbf{k}E_{fz}^x. \tag{3}$$

Here again the superscript denotes the direction of polarization. Using (1), (2) and (3) the co-polar voltage can be written as:

$$V_{\text{co-pol}} = c \iint_S \mathbf{E}_r^x . \mathbf{E}_f^x \, e^{-j\delta} \mathbf{r} . d\mathbf{S}. \tag{4}$$

In order to determine the cross-polar voltage, either of two conventions can be followed: (i) 'Rotate' the incident polarization through an angle of $\pi/2$ radians keeping the feed polarization function unchanged. (ii) 'Rotate' the feed and maintain the polarization of the incident field. Using the first convention the equation for $\mathbf{E}_r$ becomes

$$\mathbf{E}_r^y = \mathbf{i}E_{rx}^y + \mathbf{j}E_{ry}^y + \mathbf{k}E_{rz}^y. \tag{5}$$

Hence, the voltage due to the cross-polarized field can be written as

$$V_{\text{cross-pol}} = c \iint_S \mathbf{E}_r^y . \mathbf{E}_f^x \, e^{-j\delta} \mathbf{r} . d\mathbf{S}. \tag{6}$$

If convention (ii) is used then the following expression is readily obtained

$$V_{\text{cross-pol}} = c \iint_S \mathbf{E}_r^x . \mathbf{E}_f^y \, e^{-j\delta} \mathbf{r} . d\mathbf{S}. \tag{7}$$

Using (4), (6) and (7) the cross-polarization isolation as defined in reference 1 can be written as:

$$\text{Isolation (dB)} = 20 \log_{10} \left| \frac{\text{peak } V_{\text{co-pol}}}{V_{\text{cross-pol}}} \right|$$

$$= 20 \log_{10} \left| \frac{\iint \mathbf{E}_r^x . \mathbf{E}_f^x \mathbf{r} . d\mathbf{S}}{\iint \mathbf{E}_r^y . \mathbf{E}_f^x \, e^{-j\delta} \mathbf{r} . d\mathbf{S}} \right|$$

$$= 20 \log_{10} \left| \frac{\iint \mathbf{E}_r^x . \mathbf{E}_f^x \mathbf{r} . d\mathbf{S}}{\iint \mathbf{E}_r^x . \mathbf{E}_f^y \, e^{-j\delta} \mathbf{r} . d\mathbf{S}} \right| \tag{8}$$

It is worth noting that the above expressions for $V_{\text{co-pol}}$, $V_{\text{cross-pol}}$ and isolation are valid irrespective of the way cross-polarization is defined.

2.3 Cross-polarization Voltage Reduction

Consider expressions (6) and (7) for the cross-polar voltage. It is obvious from these expressions that the condition for zero cross-polarization is

$$\mathbf{E}_r^x . \mathbf{E}_f^y = \mathbf{E}_r^y . \mathbf{E}_f^x = 0. \tag{9}$$

The physical interpretation of this is that the field due to the reflector when receiving a wave of a particular polarization should be orthogonal everywhere to the field transmitted by the feed when cross-polarized with respect to the incident field.

Theoretically a Huygens source satisfies this condition when placed at the focus.[10] The Huygens source is a conceptual antenna, however it has been recently reported by Cowan[13] that choked circular waveguides provide close approximation to the ideal pattern.

Now, consider the expanded form of equation (9), we have:

$$\mathbf{E}_r^x . \mathbf{E}_f^y = \mathbf{E}_{rx}^x \mathbf{E}_{fx}^y + \mathbf{E}_{ry}^x \mathbf{E}_{fy}^y + \mathbf{E}_{rz}^x \mathbf{E}_{fz}^y. \tag{10}$$

As an alternative to using a Huygens source a method for cross-polarization reduction is to minimize the absolute value of each term in (10) separately, thus:

$$|\mathbf{E}_r^x . \mathbf{E}_f^y|_{\min} \leqslant |E_{rx}^x E_{fx}^y|_{\min} + |E_{ry}^x E_{fy}^y|_{\min} + |E_{rz}^x E_{fz}^y|_{\min} \tag{11}$$

It is noted that E_{fx}^y and E_{ry}^x are the cross-polarized field components due to the feed and reflector respectively. On the other hand E_{rz}^x and E_{fz}^y are the corresponding z-components.

In order that cross-polarization should be brought to a minimum we require that E_{fx}^y, E_{ry}^x, E_{fz}^y and E_{rz}^x should all be minimized. Note that E_{rx}^x and E_{fy}^y represent the co-polar field components and we require them to be large. For E_{fx}^y to be minimum we need a low cross-polarization feed. E_{ry}^x can be minimized by using a double reflector system, i.e. Cassegrain. For E_{fz}^y and E_{rz}^x to be minimized, the angle subtended by the reflector at the feed should be small. This leads to the following important results.

Cross-polarization can be minimized by use of:

(1) Low cross-polarization due to primary feed.

(2) Low cross-polarization due to reflecting system.

(3) Large f/D ratio.

Perhaps it should be mentioned that the Cassegrain geometry satisfies the last two requirements simultaneously. This is so since the reflecting system introduces very little cross-polarization;[1] also introducing the sub-reflector increases the focal length to diameter ratio. The first requirement is again indirectly satisfied. This is so since horns as well as dipole feeds have little cross-polarization for small off-axis angles and since the angle subtended at the focus by the subreflector is small it follows that the total cross-polarization of the system is reduced.

It is worth noting that the above methods of cross-polarization reduction are based on the classical definition of cross-polarization. If Ludwig's third definition[7] is used then the reflector introduces no cross-polarization (edge diffraction being neglected). The field due to the feed can therefore be written as

$$\mathbf{E}_f^x = \mathbf{E}_{f\parallel}^x + \mathbf{E}_{f\perp}^x$$

where $\mathbf{E}_{f\parallel}^x$ and $\mathbf{E}_{f\perp}^x$ are the components parallel and normal to $\mathbf{E}_r$, i.e. co-polar and cross-polar components. The expressions for $V_{\text{co-pol}}$ and $V_{\text{cross-pol}}$ can now be written as:

$$V_{\text{co-pol}} = c \iint_s \mathbf{E}_r^x . \mathbf{E}_f^x \, e^{-j\delta} \mathbf{r} . d\mathbf{S}$$
$$= c \iint_s |\mathbf{E}_r^x| \, |\mathbf{E}_{f\parallel}^x| \, e^{-j\delta} \mathbf{r} . d\mathbf{S}. \qquad (12)$$

Similarly

$$V_{\text{cross-pol}} = c \iint_s |\mathbf{E}_r^y| \, |\mathbf{E}_{f\perp}^x| \, e^{-j\delta} \mathbf{r} . d\mathbf{S}. \qquad (13)$$

Thus if $V_{\text{cross-pol}}$ is to vanish, then the condition $|\mathbf{E}_{f\perp}| = 0$ must be satisfied. In other words cross-polarization can be reduced only by making $|\mathbf{E}_{f\perp}^x|$ as small as possible. Physically this requires that the primary feed should have a polarization function that is very close to that of a Huygens source.

Finally, perhaps it should be mentioned that in discussing methods of cross-polarization reduction we considered only the possibilities of minimizing the integrands in the cross-polar voltage expressions. A further possibility that should not be overlooked is that of the total integral vanishing, i.e. instead of having $\mathbf{E}_r^x . \mathbf{E}_f^y = 0$, the condition for zero cross-polarization becomes

$$\iint_s \mathbf{E}_r^x . \mathbf{E}_f^y \, e^{-j\delta} \mathbf{r} . d\mathbf{S} = 0 \qquad \text{for all } \delta.$$

The last condition requires that the field distribution in the aperture of the primary feed should be identical to that of the diffraction image in the focal plane of the reflector when excited by a plane wave. This focal plane approach was discussed by Ghobrial[11, 12] and more recently by Poultan and Claydon.[4]

3 Numerical Results for Typical Systems

To check the results obtained above the radiation patterns of Cassegrain-fed and front-fed antennas were calculated using two types of feeds: (i) electric dipole, (ii) rectangular horn. In both cases (Cassegrainian and front fed) the f/D for the paraboloid was taken as 0·46. This figure was chosen to allow us to compare the obtained results with previously published data.[10] From the reciprocity theorem for antennas we expect the results obtained for receiving antennas using the present method and those obtained for transmitting antennas to be the same. This is indeed what was found.

3.1 Paraboloid Fed by a Short Dipole

The first column of Table 1 gives computed characteristics of a paraboloid fed by a dipole using the present method. The second column gives the corresponding values from Table 1 in the paper by Jones[10] for a transmitting paraboloid. It is seen that the agreement is excellent.

3.2 Cassegrain Fed by a Short Dipole

Although it is not the usual practice to feed a Cassegrain system by a dipole in view of the small angle subtended by the subreflector at the focus and the low directivity of the dipole, yet to illustrate the point discussed in Section 2 the radiation patterns of a Cassegrain fed by a dipole were computed. The last column in Table 1 gives the results obtained. It is seen that maximum cross-polarization level is −58 dB which confirms the conclusions cited in Section 2.

3.3 Rectangular Horn Feed

Using the same technique the radiation patterns of front fed and Cassegrainian fed antennas excited by a rectangular horn were computed. Table 2 gives computed and measured pattern characteristics.[14]

The system for which the above results apply had the following geometry:

paraboloid diameter	121·9λ
focal length	40·3λ
angular semi-aperture	74·2°
hyperboloid diameter	11·85λ
eccentricity	1·198

The discrepancy between theory and practice in cross-polarization level for the Cassegrain system can be attributed to edge diffraction effects from subreflector and support struts which were not taken into account in these calculations. This also explains why the first cross-polar maximum is on beam; diffraction from edges and support struts need not be axially symmetrical.

Table 1

Computed pattern characteristics for a paraboloid excited by a short dipole ($D/\lambda = 37·2$)

Characteristic	Front-fed paraboloid		Cassegrainian fed paraboloid
	Present method	Jones results	
H-plane half power beamwidth	1·6°	1·6°	1·57°
E-plane half power beamwidth	1·7°	1·75°	1·57°
Position of cross-polarization maximum	1·84°	1·8°	1·83°
H-plane first side lobe level	−17·68 dB	−17·2 dB	−16·3 dB
E-plane first side lobe level	−23·0 dB	−22·9 dB	−16·6 dB
Cross-polarized lobe max level	−24·6 dB	−24·3 dB	−58·0 dB

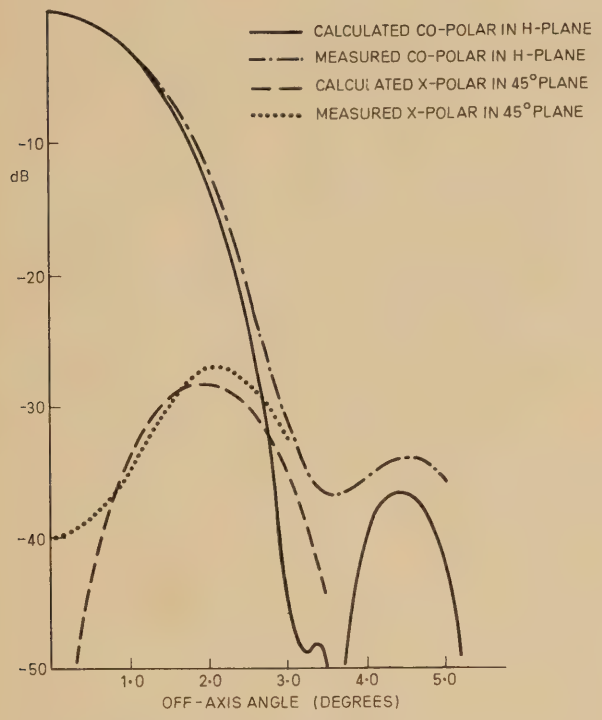

Fig. 1. Calculated and measured patterns of a reflector of 57° angular semi-aperture front-fed by a rectangular horn.

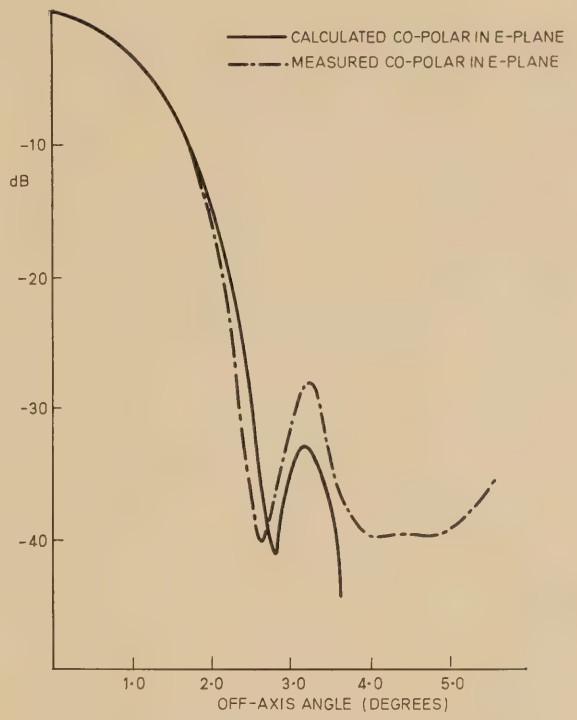

Fig. 2. E-plane patterns of the system of Fig. 1.

Figures 1 and 2 give measured radiation patterns of a reflector antenna with an angular semi-aperture of 57·0°. The primary feed used was a rectangular horn that produced an average of 21 dB taper at the edges of the reflector. Theoretical curves are also included for comparison. The latter were obtained using equations (4) and (6). It is seen that the agreement is good. In particular the positions of co-polar nulls and side-lobes are accurately predicted. The fact that measured cross-polar is not zero along bore-sight (on beam) may be attributed to edge diffraction as before. This may also be due to receiver noise which also explains why the co-polar nulls are at the same level (−40 dB) as the cross polar null. It is also worth mention that reflector surface errors may result in similar effects, i.e. non-zero cross-polarization on axis.[15]

4 Conclusions

A method for calculating the co-polar and cross-polar patterns of reflector antennas when operated in the receive mode has been discussed and a formula for cross-polarization isolation derived. Methods for cross-polarization reduction were discussed in the light of the results obtained. It has been shown that the condition for zero cross-polarization is that the field due to the feed when transmitting and that due to the reflector when receiving should be orthogonal. A Huygens source satisfies this condition. Alternative methods for cross-polarization reduction include: (i) low cross-polarization due to feed, (ii) low cross-polarization due to reflector, (iii) large f/D ratio. It has been shown that the Cassegrain geometry satisfies these conditions. Cross-polarization can also be reduced by using a feed the field at the aperture of which is identical to that of the focal plane diffraction image when the reflector is excited by a plane wave.

5 Acknowledgments

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Table 2

Computed and measured characteristics for a paraboloid excited by a rectangular horn

Characteristics	Front fed		Cassegrainian fed	
	Computed	Measured	Computed	Measured
E-plane half power beamwidth	0·875°	0·9°	0·48°	0·48°
E-plane first side lobe level	−27·6 dB	−10·5 dB	−17·0 dB	−13·0 dB
Position of cross-polarization maximum	0·95°	1·08°	0·4°	0·0°
Cross-polarization maximum level	−27·8 dB	−23·8 dB	−58·6 dB	−42·0 dB

Electronic Engineering at the University of Bradford, for allowing him to use computer facilities. Thanks are also due to Dr. P. A. Watson for his encouragement and for allowing the author to quote the measured results given in Table 2.

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Standard Frequency Transmissions—May 1975

(Communication from the National Physical Laboratory)

May 1975	Deviation from nominal frequency in parts in 10^{10} (24-hour mean centred on 0300 UT)	Relative phase readings in microseconds NPL—Station (Readings at 1500 UT)	
	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz
1	0	686·2	605·5
2	0	686·2	605·6
3	0	686.0	605·5
4	−0·1	685·4	605·4
5	0	686·0	605·4
6	0	686·2	605·4
7	−0·1	686·0	605·5
8	0	685·6	605·7
9	−0·1	685·8	605·7
10	−0·1	685·6	605·8
11	−0·2	685·6	605·8
12	−0·1	685·8	605·8
13	−0·1	685·8	605·8
14	−0·1	685·8	605·9
15	−0·1	685·8	606·0
16	−0·1	686·0	606·1
17	−0·1	686·2	606·2
18	−0·2	686·4	606·4
19	−0·2	686·2	606·7
20	−0·3	686·4	606·5
21	−0·3	686·2	606·7
22	−0·3	686·8	606·9
23	−0·2	686·6	606·9
24	−0·3	686·6	607·1
25	−0·3	686·8	607·2
26	−0·2	686·8	607·5
27	−0·2	686·6	607·3
28	−0·3	686·6	607·1
29	−0·2	686·8	607·2
30	0	687·4	607·2
31	−0·2	686·6	607·3

All measurements in terms of H-P Caesium Standard No. 334, agrees with the NPL Caesium Standard to 1 part in 10^{11}.

* Relative to UTC Scale; (UTC_{NPL}–Station)
$= +500$ at 1500 UT 31 December 1968.

† Relative to AT Scale; (AT_{PNL}–Station)
$= +468{\cdot}6$ at 1500 UT 31 December 1968.

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Analysis of a dual frequency moving target indication system

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SUMMARY

The problem of a two-frequency m.t.i. system is formulated for a general case. It is concluded that: (a) The two-frequency m.t.i. system sees an increased clutter Doppler variance as compared to that of a single frequency system. (From σ^2 to $\sigma^2(1 + r^2)$ where r is the ratio of the carrier frequencies in the two frequency channels.) (b) The mean clutter-Doppler frequency, at the same time, is reduced accordingly from f_0 to $f_0(1 - r)$.

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1 Introduction

It is well known that a radar moving target indicator system performs better at a lower radar frequency. However, other considerations require that a modern radar be operated at a high frequency, usually in the microwave range. This generally presents a difficult problem in the design of an m.t.i. system, particularly if the radar system is required to reject a clutter of wide Doppler spread at the same time it is required to detect a high-speed target. It has been suggested that a dual-frequency m.t.i. system may be a solution to this problem. A possible configuration is shown in Fig. 1. The mixing of the two radar returns from two different frequency channels generates two frequency components, the sum and difference of the Doppler frequencies from both frequency channels. The sum frequency component can be filtered out before it is converted to the base band. The difference frequency component, after being shifted to base band, has a net effect of shifting the signal-Doppler frequency to the difference of the Doppler frequencies in the two channels. If the two carrier frequencies are closely spaced, the difference of the Doppler frequencies will be small. Thus, this system effectively reduces the target Doppler frequency by a large factor, which is equivalent to operating the radar system at a lower frequency. This should improve m.t.i. performance. Unfortunately, such an intuitively simple explanation does not take all the facts into account. The fact is that since the radar return contains both target and clutter, mixing of the two returns generates not only the beat-frequency components of clutter-to-clutter and target-to-target but also the clutter-to-target from both channels. Due to the fact that the clutter-Doppler frequency usually is very low, the frequency component of the beat of the target-to-clutter Doppler is high and comparable to that of a single frequency system. Furthermore, because the spectrum of the clutter returns is Gaussian, the resultant clutter Doppler spectrum corresponding to the difference frequency is also Gaussian. It should be noted, however, that the variance of the clutter Doppler after taking the difference frequency is the sum of the clutter Doppler variances at each frequency. Thus, as it compares to a single-frequency m.t.i. system, the clutter spectrum of the dual frequency m.t.i. is wider.

An analysis of the performance of this kind of m.t.i. system has been conducted by Kroszczynski.[1,2] Unfortunately, Kroszczynski's analysis is based on the assumption that the clutter return has only a single Doppler frequency, hence it is difficult to examine the above effect. Furthermore, Kroszczynski's result is not in a convenient form to compare with a conventional single-frequency m.t.i. system. In this paper we shall attempt to treat this subject in more general terms. We shall find its optimal improvement factor so that a direct comparison with a single frequency m.t.i. system is then possible.

2 Improvement Factor

The dual-frequency m.t.i. system to be analysed here has a configuration as shown in Fig. 1. The radar returns from both frequency channels contain clutter, system

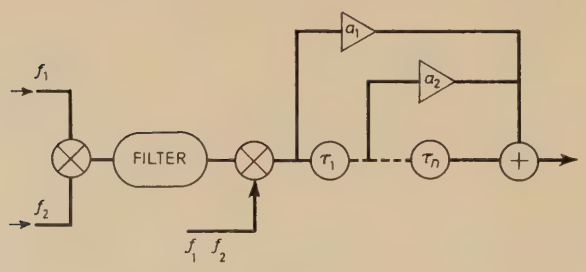

Fig. 1. A dual frequency m.t.i. system.

noise, and target signals. Let us first assume that the power spectrum function of the clutter returns is Gaussian with zero mean and standard deviations σ_1 and σ_2. The subscripts $_1$ and $_2$ are used here to represent the returns from frequency channels f_1 and f_2. Hence, we have

$$G_1(f_1) = \frac{1}{\sqrt{2\pi\sigma_1}} \exp\left(-\frac{f_1^2}{2\sigma_1^2}\right) \tag{1a}$$

$$G_2(f_2) = \frac{1}{\sqrt{2\pi\sigma_2}} \exp\left(-\frac{f_2^2}{2\sigma_2^2}\right) \tag{1b}$$

Without losing generality, let us assume the power spectrum of the target return to be an impulse function,

$$T_1(f) = \delta(f-f_{1s}) \tag{2a}$$

$$T_2(f) = \delta(f-f_{2s}) \tag{2b}$$

where f_{1s} and f_{2s} represent the Doppler frequencies of the target from the two frequency channels. Let us assume the thermal noise in the radar system to be white and with a constant spectrum density.

Quantities σ_1, σ_2, f_{1s}, and f_{2s} are related by the following relation:

$$\frac{\sigma_1}{\sigma_2} = \frac{f_{1s}}{f_{2s}} = \frac{f_{1c}}{f_{2c}} = r \tag{3}$$

where f_{1c} and f_{2c} are the radar carrier frequencies in the two channels.

The radar returns from the two frequency channels can be assumed to be two independent random processes. The output power spectra from the mixer are the convolutional products of the power spectra from the two channels.[3] Let the relative power levels of the clutter, target, and noise in the two channels be C_1, C_2, E_1, E_2, N_1, and N_2. The resultant power spectrum then contains nine terms; they are:

(1) Product of clutter returns

$$C = \frac{C_1C_2}{\sqrt{2\pi}\sqrt{\sigma_1^2+\sigma_2^2}} \exp\left\{-\frac{f^2}{2(\sigma_1^2+\sigma_2^2)}\right\}. \tag{4a}$$

(2) Product of clutter and target

$$E_c = \frac{E_1C_2}{\sqrt{2\pi\sigma_2^2}} \exp\left\{-\frac{(f-f_{1s})^2}{2\sigma_2^2}\right\} + \frac{E_2C_1}{\sqrt{2\pi\sigma_1^2}} \exp\left\{-\frac{(f-f_{2s})^2}{2\sigma_1^2}\right\}. \tag{4b}$$

(3) Product of target signals from both channels

$$E_e = E_1E_2\delta[f-(f_{1s}-f_{2s})]. \tag{4c}$$

(4) Products of clutter and noise

$$N_c = N_1C_2+N_2C_1. \tag{4d}$$

(5) Products of target and noise

$$E_n = N_1E_2+N_2E_1. \tag{4e}$$

(6) Products of noises

$$N_n = N_1N_2. \tag{4f}$$

One notices that if a target is absent, the terms E_c, E_e and E_n become zero. Therefore, one may treat these terms as target signals.

Let us assume that the transmitted waveforms in both frequency channels are identical and consist of a train of N coherent pulses uniformly spaced at times T_1, T_2, ..., T_N. These N returns from one range resolution cell are then weighted and summed. Let these weights be represented as a_is. The covariance of this sequence of samples is

$$R(T_i, T_j) = \sum_{i,j} a_i a_j^* \int_{-\infty}^{\infty} G(f) \exp[j2\pi f(T_i-T_j)]\, df$$

where $G(f)$ is the spectrum density function which contains nine terms as noted earlier. Insert these terms into this equation, then change the order of integration and summation. After performing the integration and separating the part due to signal and clutter one finds

$$R_{cn}(T_i, T_j) = \sum_{ij} a_i a_j^*[C_1C_2P_{ij}+N_1N_2\delta_{ij}+ +C_1N_2\delta_{ij}+C_2N_1\delta_{ij}] \tag{5a}$$

$$R_s(T_i, T_j) = \sum a_i a_j^*[C_1E_2S_{ij}(c_1; e_2)+ +C_2E_1S_{ij}(c_2; e_1)+N_1E_2\delta_{ij}+N_2E_1\delta_{ij}+ +E_1E_2S_{ij}(e_1; e_2)] \tag{5b}$$

where

$$P_{ij} = \exp[-2\pi^2(\sigma_1^2+\sigma_2^2)T_{ij}^2] \tag{6a}$$

$$S_{ij}(c_1; e_2) = \cos(2\pi f_{2s}T_{ij}) \exp[-2\pi^2\sigma_1^2T_{ij}^2] \tag{6b}$$

$$S_{ij}(c_2; e_1) = \cos(2\pi f_{1s}T_{ij}) \exp[-2\pi^2\sigma_2^2T_{ij}^2] \tag{6c}$$

$$S_{ij}(e_1; e_2) = \cos 2\pi(f_{1s}-f_{2s})T_{ij} \tag{6d}$$

$$T_{ij} = T_i-T_j \tag{6e}$$

$$\delta_{ij} = 1 \quad \text{if } i = j$$
$$= 0 \quad \text{otherwise.}$$

One feature which should be pointed out is that if the carrier frequencies in both channels are identical, then this system becomes similar to that of a non-coherent m.t.i. system, in which case the signal output comes from a square law detector. This is equivalent to mixing two identical signals. Hence, if f_{1s} is equal to f_{2s}, the target signal has zero Doppler, which will be rejected by the m.t.i. filter. Therefore, in a non-coherent m.t.i. system, targets cannot be detected in the absence of clutter. On the other hand, in this dual frequency system if $f_{1s} \neq f_{2s}$, the target signal will be present, even if clutter is absent.

To simplify the above expression, let us assume that

$$\frac{E_1}{C_1} = \frac{E_2}{C_2} = \frac{E}{C} \tag{7a}$$

$$\frac{N_1}{C_1} = \frac{N_2}{C_2} = \frac{N}{C} \tag{7b}$$

This assumption says that the power ratio of the target signal-to-clutter and that of the noise-to-clutter are invariant with respect to carrier frequency. This assumption is probably valid if the carrier frequencies in both channels are very close. In that case the antenna patterns of both channels will not be significantly different provided that the same antenna is used in both channels.

The improvement factor of this two-frequency m.t.i. system is then

$$I = \frac{\sum_{ij} R_s(T_i, T_j)}{\sum_{ij} R_{cn}(T_i, T_j)} \cdot \frac{C}{E} =$$

$$\frac{\sum_{ij} a_i a_j^* \left[S_{ij}(c_1; e_2) + S_{ij}(c_2; e_1) + \frac{2N}{C}\delta_{ij} + \frac{E}{C} S_{ij}(e_1; e_2) \right]}{\sum_{ij} a_i a_j^* \left(P_{ij} + \frac{2N}{C}\delta_{ij} + \frac{N^2}{C^2}\delta_{ij} \right)} \tag{8}$$

where the a_i are filter weights and are, in general, complex.

In the design of an m.t.i. system, the primary goal is to optimize this improvement factor. To achieve this goal, it is necessary to find a set of filter weights such that the above expression is maximum. The numerator of the above expression can be written in the following form:

$$F(f_{2s}) = \sum_{ij} a_i a_j^* \Big\{ \cos(2\pi f_{2s} T_{ij}) \exp[-2\pi^2 r^2 \sigma_2^2 T_{ij}^2] + \\ + \cos(2\pi f_{2s} r T_{ij}) \exp[-2\pi^2 \sigma_2^2 T_{ij}^2] + \\ + \frac{2N}{C}\delta_{ij} + \frac{E}{C}\cos 2\pi f_{2s}(r-1)T_{ij} \Big\} \tag{9}$$

where f_{1s} and σ_1 are replaced respectively by $f_{2s}r$ and $\sigma_2 r$. One notices that $F(f_{2s})$ is a function of the target Doppler f_{2s}. Since the target Doppler frequency is not known, in order to optimize the improvement factor one really has to choose many sets of a_i such that each set gives an optimal improvement for a given target Doppler frequency. This, in general, requires a bank of filters, each specifically designed for a particular Doppler. An alternative approach is to choose a set of weights that optimize the improvement factor with respect to the expected $F(f_{2s})$. Since the target velocity is not known, one may assume that its Doppler frequency has a uniform probability density. Hence the expected value of $F(f_{2s})$ is

$$\langle F(f_{2s}) \rangle = \sum_i |a_i|^2 \left(2 + \frac{2N}{C} + \frac{E}{C} \right). \tag{10}$$

The improvement factor hence becomes:

$$I = \frac{\sum_i |a_i|^2 \left(2 + \frac{2N}{C} + \frac{E}{C} \right)}{\sum_i \sum_j a_i a_j^* \left[P_{ij} + \frac{N}{C}\left(2 + \frac{N}{C} \right)\delta_{ij} \right]}. \tag{11a}$$

For a single frequency case, the improvement factor is[4]

$$I = \frac{\sum_i |a_i|^2}{\sum_i \sum_j a_i a_j^* \left(P'_{ij} + \frac{N}{C}\delta_{ij} \right)}. \tag{11b}$$

Assuming the mean-Doppler of clutter is zero, covariance matrix elements P_{ij} and P'_{ij} can be represented

$$P_{ij} = \exp[-2\pi^2(1+r^2)\sigma^2 T_{ij}^2] \tag{12a}$$

$$P'_{ij} = \exp[-2\pi^2 \sigma^2 T_{ij}^2]. \tag{12b}$$

Comparing equation (11a) with (11b) and equation (12a) with (12b), one finds:

(a) The improvement factor of a two-frequency m.t.i. system is a function of the clutter level and has a gain of $(2+2N/C+E/C)$ as compared to a single-frequency m.t.i. system, if other effects are ignored.

(b) The noise level of a two-frequency m.t.i. system is increased by a factor of $2+N/C$.

(c) The effective variance of the clutter spectrum is increased by a factor of $1+r^2$, r being the ratio of the radar carrier frequencies in the two frequency channels. The σ^2 (clutter-variance) measures the clutter spectral thread. It is well known that the wider the clutter spectrum spreads, the less the m.t.i. improvement factor which can be achieved.

Due to this fact, although in (a) we have stated that a two-frequency m.t.i. system has a better gain, if this increase of the effective clutter variance is considered, a single-frequency m.t.i. system actually has a better overall improvement factor. Later, we shall give a few numerical examples to compare the performance of a two-frequency m.t.i. system with that of a single-frequency m.t.i. system which will confirm this conclusion.

We pointed out earlier that the improvement factor of a two-frequency m.t.i. system is a function of the clutter level. We shall briefly discuss here its effects.

2.1 Strong Clutter

If $C \gg E$ and $C \gg N$, then the N/C and E/C terms in equation (11a) can be ignored. The improvement factor of a two-frequency m.t.i. system is then 3 dB better than that of a single-frequency m.t.i. system (ignoring the effect of clutter spectral spreading). This is what one would expect, because a two-frequency m.t.i. system contains two channels.

2.2 Weak Clutter

In this case, $N \ll C$, but $E \geqq C$. Under these conditions, the improvement factor of a two-frequency m.t.i. system can be considerably better than that of a single-frequency m.t.i. It is interesting to notice here that the improvement factor of a two-frequency m.t.i. system becomes better as the clutter becomes weaker. However, this property is not very useful. The time when the high improvement factor is needed is when the clutter is strong. Therefore, the subsequent discussion will be limited only to the case of strong clutter. Furthermore, other conditions being the same, the improvement factor for a weak clutter case can be extrapolated easily.

The noise level in a practical radar is usually small. Furthermore, the presence of thermal noise affects only the diagonal elements of the covariance matrix. If the covariance matrix is normalized with respect to this added noise, the net effect is equivalent to increasing either the σ or the correlation time T_{ij} (see ref. 4). In

the subsequent discussion on the optimization of m.t.i. improvement factor, the effect of thermal noise is neglected.

2.3 Thermal Noise Limited Case

If $N \gg C$, but $E > N$, the clutter is so weak that the thermal noise becomes the limiting factor. Under this condition, the problem becomes a classic problem of target detection in the presence of white noise. This has been well treated in the past. However, we are interested in a case when the radar is operating at an m.t.i. mode, clutters may suddenly disappear in certain range regions. We would like to know how this would affect target detections. We notice that from equation (5b) in the event of the absence of clutters, the clutter-and-target cross-product terms vanished. The only term which represents the target output is $S_{ij}(e_1, e_2)$.† This $S_{ij}(e_1, e_2)$ term has a Doppler frequency which is the difference of the target Doppler frequencies of the returns from the two-frequency channels. If the carrier frequencies of the two frequency channels are very close or the target Doppler is small, the Doppler frequency of $S_{ij}(e_1, e_2)$ may be so small that it may look like a stationary target and be rejected by the m.t.i. filter. Quantitatively, one may view that a two-frequency m.t.i. system performs a Doppler frequency transformation from f_2 to $(1-r)f_2$ where r is the ratio of the carrier frequencies in the two frequency channels. Usually, an m.t.i. filter is so designed that the radar echo having Doppler frequency falling within one standard deviation of clutter Doppler ($\sqrt{(1+r^2\sigma^2)}$ for a two-frequency m.t.i. system) is rejected. This may be used as a rule of thumb to choose the factor r. One may notice that when $r = 1$, this becomes a non-coherent m.t.i. system and it is well known that a target cannot be detected in the absence of clutter.

3 Optimization of the Improvement Factor

To optimize the improvement factor one is required to choose a set of a_i under the constraint that $\sum_i a_i^2$ is constant and which also minimizes the denominator of equation (11). This is a well-known eigen value problem. The P_{ij} are actually elements of a covariance matrix. This matrix is symmetrical and positive definite; hence its eigen values are real and positive. One of these eigen values has a minimum value. If the eigen vector associated with this minimum eigen value is chosen as the filter weight, the quadratic form $(\mathbf{a}, P\mathbf{a})$ has a minimum value and is equal to the minimum eigen value, provided that vector $\mathbf{a}$ and matrix P are properly normalized. One may notice that if $\mathbf{a}$ is normalized, this quadratic form really represents the clutter output, or the reciprocal of the improvement factor. Since the matrix P is symmetrical and positive definite, components of vector $\mathbf{a}$ are real. The improvement factor is a function of the product σT where T is the interpulse time. Its reciprocal, $1/T$, is commonly referred to as the pulse repetition frequency (p.r.f.). Therefore, this σT product may be referred to as a normalized clutter spectrum standard deviation, σ'. The improvement factor is a monotonic function of σ'.‡ Figure 2 plots the improvement factor as a function of σ' for a dual frequency m.t.i. filter. A family of curves is plotted. The number of cancelling pulses (N) is used as a parameter in this family of curves. The plots of improvement factor of a single-frequency m.t.i. filter are similar to those of a two-frequency case, except that the σ' scale is smaller by a factor of $\sqrt{(1+r^2)}$ and a 3-dB difference exists on the Y-axis due to the fact that only a single channel is present. Figure 2 shows that the improvement factor is reduced very rapidly as σ' increases. Furthermore, to achieve a reasonable improvement gain, this σ' is limited to a very small value. From this, one may conclude that the increase of effective clutter standard deviation in a two-frequency m.t.i. system is very undesirable.

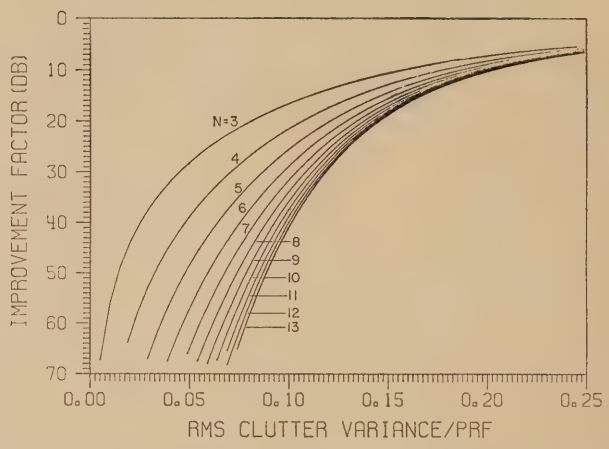

Fig. 2. Average improvement factor versus normalized r.m.s. clutter variance, N = number of cancelling pulses.

To illustrate this point, a direct comparison of a two-frequency m.t.i. system and a single-frequency m.t.i. system is shown in Fig. 3. In this figure the improvement factors of 3-pulse and 4-pulse cancellers of a single-frequency and a two-frequency m.t.i. system are plotted for the same clutter environment and p.r.f. The curves connected with triangles are those of a two-frequency m.t.i. system. It is evident that a single-frequency m.t.i. system has a better improvement factor.

4 Effect of Non-zero Mean Clutter Velocity

The covariance matrix element P_{ij} as shown in equation (6a) is rewritten in the following form when the mean Doppler is not zero:

$$P_{ij} \cos [2\pi f_{20}(1-r)T_{ij}] \exp [-2\pi^2\sigma_2^2(1+r^2)T_{ij}^2] \quad (13)$$

where f_{20} is the mean clutter-Doppler frequency in frequency channel f_2 while $f_{10} = rf_{20}$ and r is the ratio of the carrier frequencies in the two-frequency channels. It can be seen from the above expression that when f_{20} increases from zero, the value of P_{ij} is reduced when $i \neq j$. This effect is similar to that of increasing the σT product which degrades the improvement factor as discussed in the previous Section. It is then evident that for a given σT, the clutter output has a minimum value when the argument of the cosine term is zero or very

† Noise-target cross-product terms are assumed to be negligible.

‡ For detailed discussion, see ref. 4.

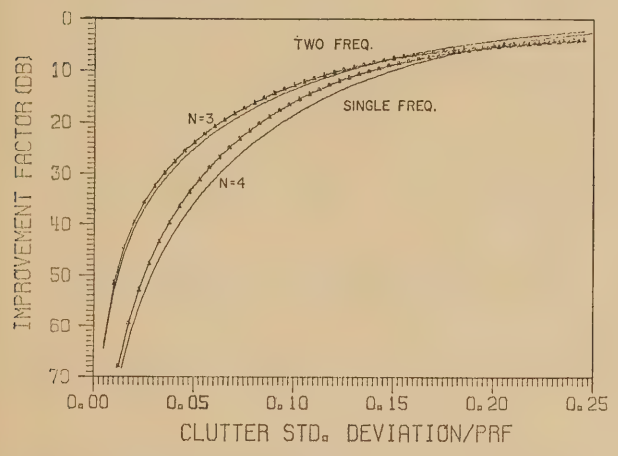

Fig. 3. Comparison of improvement factor of a two-frequency and a single-frequency m.t.i. system. $r = 1$.

small. This occurs when either f_{20} is small or the $1-r$ factor is very small. In a single frequency case, $r = 0$; therefore, the clutter output varies as f_{20} changes. On the other hand, for a two-frequency m.t.i. system, the variation of f_{20} is greatly reduced by the factor of $1-r$. This effect is shown in Fig. 4, where the average improvement factor of a 4-pulse canceller is plotted against the normalized mean-clutter Doppler frequency. The filter weights were so chosen that the canceller has an optimal improvement factor when the mean clutter Doppler frequency is zero. One may notice that when $r = 1$, the improvement factor remains constant while the normalized mean-clutter Doppler frequency varies from zero to unity. When the value of r is reduced, the degradation of the improvement factor is evident from this Figure.

5 Blind Speed

The target signal gain function as shown in equation (9) is repeated in the following:

$$G(f'_{2s}) \simeq \sum_{i,j} a_i a_j \{\cos[2\pi f'_{2s} k] \exp[-2\pi^2 r^2 \sigma'^2_2 k^2] + \cos[2\pi r f'_{2s} k] \exp[-2\pi^2 \sigma'^2_2 k^2]\} \qquad (14)$$

where $f'_{2s} = f_{2s}T$, $\sigma_2 = \sigma_2 T$, and $k = i-j$.

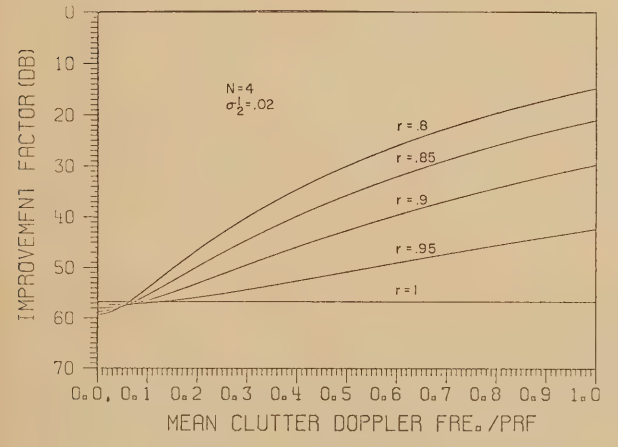

Fig. 4. Effect of mean clutter moving velocity on average improvement factor of a 4-pulse canceller.

In deriving this equation without losing generality, it has been assumed that the clutter mean Doppler frequency is zero and that $E \ll C$ so that the third and fourth terms in equation (9) can be neglected. It is evident that when

$$f'_{2s} = l_1 \qquad (15a)$$

$$f'_{2s} r = l_2 \qquad (15b)$$

where l_1 and l_2 are integers, the function $G(f'_{2s})$ repeats. Thus a dual frequency m.t.i. system has a property similar to that of a staggered p.r.f. m.t.i. system in that the separation of blind speeds is greatly extended. For example, if $r = 8/9$, the first blind speed will occur when $f'_{2s} = 9$. This is shown in Fig. 5, where the target signal shows a period when $f'_{2s} = 9$. It also shows properties similar to those of a staggered p.r.f. m.t.i. system.[5] One should notice here that for a single-frequency constant p.r.f. system this blind speed will occur at $f'_{2s} = 1$.

6 Conclusions and Discussions

In conclusion, we may state that:

(a) The clutter-Doppler standard deviation, σ, in a single-frequency m.t.i. system is changed to $\sigma\sqrt{(1+r^2)}$ in a dual-frequency system.

(b) The mean clutter-Doppler frequency of a dual-frequency m.t.i. system is changed from f_{20} in a single frequency m.t.i. to $f_{20}(1-r)$; therefore, the value of f_{20} has very little effect on the clutter output, if the value of r is close to unity and $f_{20}(1-r) \ll 1/T$.

(c) One may also notice that the target Doppler frequency is also reduced by a factor of $1-r$. In case clutter is absent, one cannot use the clutter and target and cross-correlation terms. Therefore, under this condition some low-velocity targets that can be seen in a conventional single frequency m.t.i. system may look like a stationary target to a two-frequency m.t.i. system, and be rejected, especially if r is chosen to be close to 1.

(d) Finally, from the section on 'Blind Speed', we see that a dual-frequency m.t.i. system eases the blind speed problem somewhat.

The improvement factor performance of a two-frequency m.t.i. system is compared with that of a single-frequency m.t.i. system in Fig. 3. In general, for equal values of normalized clutter standard deviation (σ/p.r.f.), a single-frequency m.t.i. system performs better than does a two-frequency m.t.i. system, particularly when the number of cancelling pulses is large. As far as clutter rejection is concerned, it seems that there is no advantage in using a two-frequency m.t.i. system. However, in a situation in which the mean clutter-Doppler varies widely and cannot be effectively compensated by other means, it is probably worthwhile to trade a few dB loss in improvement factor to gain the advantage of automatic compensation of the variations of the mean clutter-Doppler. This effect of mean clutter-Doppler compensation is illustrated in Fig. 4.

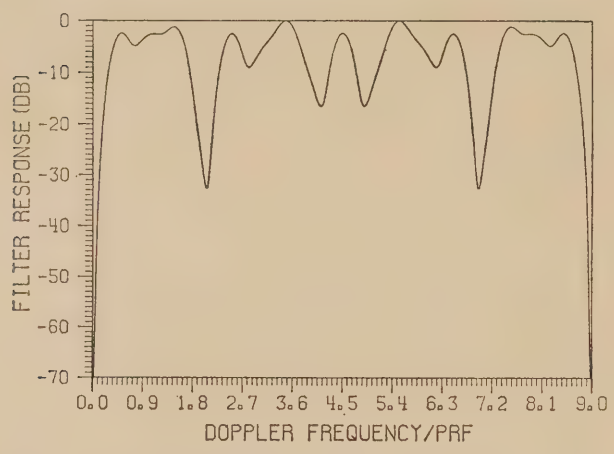

Fig. 5. Target signal gain function of a dual frequency m.t.i. system $N = 4$, $\sigma'_{20} = 0{\cdot}01$, $r = 0{\cdot}89$.

The effect of a dual-frequency m.t.i. on blind velocities is shown in Fig. 5. The response is similar to that of a staggered-p.r.f. m.t.i. system. In this plot no effort has been made to smooth out the passband variations. Conceivably, one may choose a good frequency ratio r which may yield a better result. However, if this were compared with a staggered-p.r.f., single-frequency system, one would expect that it probably would be less efficient in the sense that there is only one parameter which could be varied while in a staggered-p.r.f. system with a long train of pulses far more parameters could be varied.

In summary, we notice that the choice of the factor r has effects on the mean-Doppler compensation, the improvement of blind velocity and the effective clutter spectrum spread. Finally, we also notice that the factor r has effects on the target detection in the event of the absence of clutter. The required r value may be in conflict in the above requirement. Therefore, its choice must be a compromise in all situations.

7 Acknowledgment

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Diversity techniques for mobile radio reception

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SUMMARY

After discussing the nature of the electromagnetic field in urban environments, and the use of diversity techniques in fading media, the paper presents a survey of these techniques as applied to mobile radio, with emphasis on systems designed for analogue communication. It includes a unified approach to systems based on the double-heterodyne phase-stripper principle. The discussion is not restricted to present-day receivers only, but includes considerations which may apply in future designs.

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1 Introduction

During the last 30 years, there has been a rapid expansion in the use of mobile radio, for both civilian and military purposes. Since the portions of the radio spectrum available for this type of communication have not been expanded in proportion to the number of users, channel separation has been progressively reduced. The users have also come to expect a higher quality of service, regions of poor reception well within the nominal coverage area of a base station not being readily tolerated; such regions are most likely to occur in urban and wooded areas. Because of interference and the mounting concern about electromagnetic pollution, this problem cannot be solved by indiscriminate increases in transmitter power. Although the majority of users still requires analogue communications, the demand for data transmission is likely to increase in the future, and this will place even more stringent requirements on the quality of the channel.

Diversity reception is one way to improve the reliability of communication without increasing either the transmitted power, or bandwidth.

This paper reviews the nature of the electromagnetic field in urban environments, and the use of diversity in fading media; it also provides a survey of techniques by which diversity reception systems can be implemented for mobile radio use. The stress is on analogue communication, but most of the systems can, in principle, be used for the reception of data.

2 The Field in Urban Environments

A situation which often occurs in land-based mobile radio links is that an elevated base station on a good site attempts to control a number of vehicles located some distance away. Due to natural and man-made obstacles, there is often no direct line of sight path between transmitter and receiver and as the vehicle moves, the received signal fluctuates or fades. There are two approximately separable effects known as fast and slow fading. Fast fading is characterized by deep fades which occur within fractions of a wavelength and is caused by multiple reflexions from buildings and other obstacles in close proximity to the vehicle. It is most severe in heavily built-up areas where the number of waves arriving from different directions with different amplitudes and phases is often sufficient to cause the signal amplitude to follow a Rayleigh distribution over relatively small distances. However, it also occurs to various degrees in suburban and wooded areas.

When the fast fading is removed by averaging over distances of the order of tens of wavelengths, a so-called slow fading is still apparent. This is caused by variations in both the terrain profile and the general nature of the environment. The averaged signal strength in urban areas can be as much as 50 dB below the value predicted by computing the free-space path loss and is found to have a log-normal distribution with a standard deviation between 5 and 10 dB.

The signal received in an urban area is therefore locally Rayleigh with the mean of this process varying

slowly with position. A vehicle moving through this spatially-varying field experiences a fading rate proportional to its speed and the transmission frequency. At 48 km/h (30 miles/h) the fading rate is about 10 Hz per 100 MHz transmission frequency and is associated with a Doppler spread in the received spectrum.

Although there is no satisfactory mathematical model to explain the behaviour of the slow-fading, the log-normal distribution being the best-fit to experimental data, several models[1, 2] have been proposed for the local fast fading, the most useful probably being that of Clarke.[3] He assumes that for vertically polarized transmissions the field at any receiving point is also vertically polarized, and is composed of N equal-amplitude plane waves, the rth wave arriving at an angle α_r with respect to an arbitrary spatial axis in the horizontal plane, with a phase angle ϕ_r relative to an arbitrary reference. With the further assumption that the phase angles ϕ_r are independent of each other and of the spatial angles α_r, Clarke is able to predict the Rayleigh distribution of the received signal strength, the base-band spectrum received as a result of motion through the fading field, and the spatial correlation functions of the envelopes of the various field components. The predictions fit well with experimental data collected in areas where there is no direct wave from the transmitter. Based on this work, Gans has produced a power spectral theory[4] and more general work has been reported by Lin.[5]

A further physical insight into the nature of the field has been provided by the work of Cox.[6–9] He conducted experiments at 910 MHz, which yielded statistical descriptions of the time delays and Doppler shifts associated with propagation in urban and suburban environments. The results show that the typical delay spread is about 0·25 μs and the coherence bandwidth at 0·9 correlation coefficient is greater than 250 kHz. However, in some extreme cases significant signal amplitudes with excess delays up to 7 μs were recorded, and in many instances it was possible to identify the actual buildings from which reflected signals were received. This work also yielded various other statistical parameters of the propagation link and showed that whereas the signal amplitude at fixed delays often had a Rayleigh distribution, large departures from the Rayleigh also occurred.

3 Diversity Reception

In a situation where the received signal is subject to fading, some kind of diversity reception can be employed to reduce the depth and duration of fades and hence improve the quality of communication. For example, if two signals with uncorrelated envelopes can be obtained, then in Rayleigh fading conditions the probability of occurrence of simultaneous fades in excess of 20 dB is 0·01% whereas for a single signal it is 1%. It is thus clear that a signal composed of a suitable combination of the two independently fading components will have much less severe fading properties than either signal alone.

Spatial correlation functions based on expressions derived by Clarke are shown in Fig. 1, and give an indication of how almost independently fading signals can be obtained on a vehicle. The autocorrelation coefficient of both the electric and magnetic fields is less than 0·2 at displacements greater than $\lambda/4$, and thus it is reasonable to suppose that omnidirectional electric- or magnetic-field sensing aerials spaced at least $\lambda/4$ apart will receive signals suitable for a diversity system. It is worth noting that completely uncorrelated signals are not necessary; it has been shown[10] that the efficiency of a two-branch diversity receiver is negligibly impaired if the correlation coefficients between the signals on the branches are less than 0·3, and much of the diversity advantage is still apparent with correlation coefficients as high as 0·7. Figure 1 also shows that at zero separation the electric and magnetic fields are uncorrelated, and this indicates the possibility of a field-diversity system using an aerial capable of independently receiving the electric and magnetic components of the field. Lee[11] has built and tested such an aerial and demonstrated its usefulness in a type of diversity receiver which will be described later. Frequency diversity is also theoretically possible since Cox has shown that the coherence bandwidth is not high. However, because of the congested spectrum this is not really a practicable proposition. Neither is it likely that there is sufficient depolarization along the various transmission paths to make polarization diversity a viable solution, although experiments using two transmissions with different polarizations have shown promise.[12]

Space diversity transmission from the base station may be used as an alternative to diversity reception at the mobile and the economic implications of this are discussed in Section 5. For the return link, it is possible to use diversity reception at the base station. Since the major reflecting surfaces are close to the mobile, the aerial separation required at the base station is quite large, probably tens of wavelengths,[13] but there is no reason in principle why the diversity reception techniques described in this paper cannot be applied at the base station.

Diversity reception methods are usually classified in the literature in three categories as selection diversity,

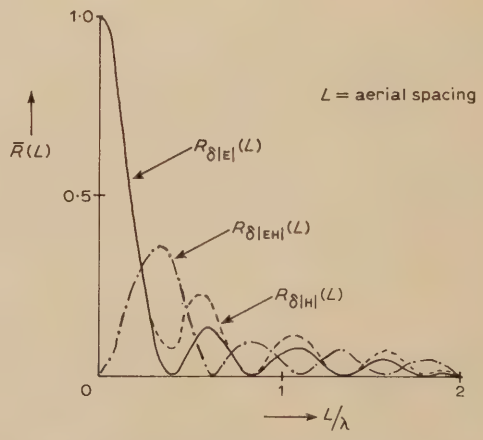


Fig. 1. Normalized autocorrelation functions for the envelopes of isotropically scattered waves.

equal-gain combining, and maximal-ratio combining; all three methods are relatively easy to realize in a practical form. As far as the combining methods are concerned, it is irrelevant in principle whether combining takes place before or after demodulation when the demodulation process is linear, but of vital concern, for example, in systems employing frequency modulation, where the demodulation process is inherently non-linear.[14] In this case pre-detection combining yields a higher baseband signal/noise ratio (s.n.r.) than post-detection combining, and since most of the world's mobile radio systems use frequency modulation it is pre-detection combining which is of major interest.

In ideal selection diversity, the signal with the highest instantaneous s.n.r. is used and so the output s.n.r. is equal to that of the best incoming signal. In practice the system cannot function on a truly instantaneous basis, and so to be successful it is essential that the internal time-constants of a selection combiner are substantially shorter than the reciprocal of the signal fading rate. Whether this can be achieved depends upon the bandwidth available in the receiving system. Practical systems of this type usually select the branch with the highest signal plus noise or utilize a simpler technique known as scanning diversity. In scanning diversity a selector scans the various branches in a fixed sequence until a signal above a predetermined threshold is found. This signal is then used until it drops below the threshold, when the scanning process restarts and continues until another acceptable signal is found. There is no attempt to find the best signal, merely one which is acceptable.

In maximal ratio combining, first proposed by Kahn,[15] each signal is weighted in proportion to its s.n.r. before summation. When this takes place before demodulation it is necessary to co-phase the individual signals before combining, and various techniques for doing this will be described. Ideally, maximal ratio combining produces an output s.n.r. equal to the sum of the individual s.n.r.s, and is the best that can be achieved. Although the technique involves some complexity in the form of the weighting, co-phasing, and summing circuits, it has the advantage that it is possible to produce an output with an acceptable s.n.r. even when none of the signals on the individual branches are themselves acceptable. This, of course, is not possible with selection diversity.

Equal gain combining is similar to maximal ratio, but there is no attempt at weighting the signals before addition. The possibility of producing an acceptable signal from a number of unacceptable inputs is retained, and the performance is only marginally inferior to that of maximal ratio combining.

The effectiveness of diversity can be assessed in a number of ways.[10] Most important as far as mobile radio is concerned is its ability to increase the reliability of communication by reducing the depth and rate of fading. Figure 2 shows theoretical cumulative probability distribution functions for two-branch diversity systems, assuming equal, locally-incoherent noise powers on each branch, with the Rayleigh fading characteristic shown for comparison. Clearly diversity has most to offer at low signal levels, and taking the equal-gain case

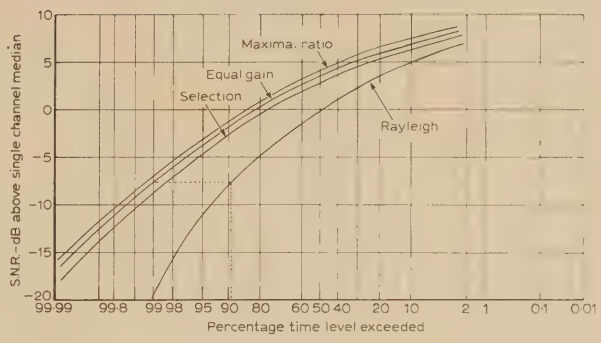


Fig. 2. Theoretical cumulative probability distributions for two-branch diversity systems.

as an example, it can be seen that the predicted reliability of a two-branch system is 99% in circumstances in which a single-aerial system would be only about 88% reliable. This means that for a fixed transmitter power, the coverage of the service area is far more 'solid', and there are far fewer areas in which signal flutter causes poor reception. This may be very significant in radio links designed to carry data transmissions, especially since it can also be shown that if all branches are statistically alike, the average fade duration below any particular reference level is reduced by a factor equal to the number of diversity branches used.[16] To achieve the same result by altering the transmitter power would involve an increase of 12 dB, which would be both costly and socially undesirable. Although strictly speaking the above figures are only valid in areas where there is Rayleigh fading, in practice the detailed nature of the fading is relatively unimportant and it is only when there is a strong direct wave from the transmitter (in which case diversity has little to offer) that there is any serious error.

Equal-gain and maximal ratio combiners attempt to add the noises incoherently, whilst providing coherent addition of the signals. We have already stated that little degradation of performance results if the inputs have low correlations. However, in unfavourable conditions where the noise inputs may be highly correlated (e.g. ignition interference) maximal-ratio combining, far from being the ideal diversity combiner may in fact turn out to provide the lowest s.n.r. with respect to the wanted output, since correlated noise appears as signal to this kind of receiving system. Selection diversity is the optimum technique in this case.[16] Because field conditions of various kinds can occur in mobile radio, and since the main advantage of diversity arises from making the best use of the strongest signal branch, the relatively minor differences between the various techniques are not important. No one technique can be said to be superior to the others in all conditions, even if the system realization is ideal.

4 Diversity Reception Systems

Having obtained signals which are sufficiently decorrelated, the task of the diversity receiver is to use them in a way which will provide the optimum benefit. There are many ways in which the signals from the various

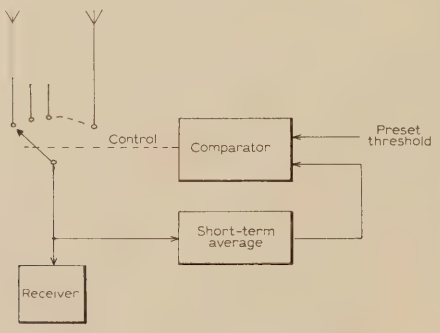
branches can be processed, and practical systems based on the techniques mentioned above will be described in this Section.

4.1 Systems using Single Conventional Receivers

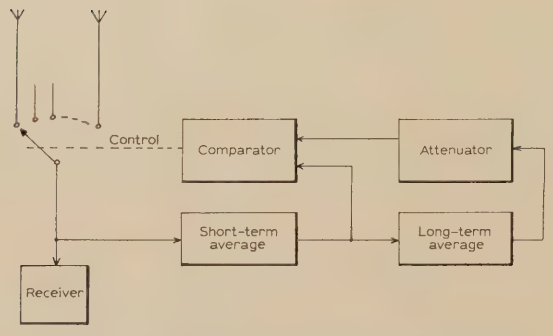
4.1.1 *Switched diversity*

Selection diversity and its derivative scanning diversity are both switched systems in the sense that one of a number of possible inputs is allowed into the receiver. A major disadvantage of implementing true selection diversity is the expense of continuously monitoring the signals on all the branches, and this makes it impracticable for mobile use. On the other hand, scanning diversity is inherently cheap to build, since irrespective of the number of branches it requires only one circuit to measure the short-term average power of the signal actually being used. Switching occurs when the output of this circuit falls below a threshold. In this context 'short-term' refers to a period which is small compared with the time taken by the vehicle to travel a significant fraction of a wavelength. A basic form of scanning diversity is shown in Fig. 3(a), although of course it is not essential for the averaging circuit to be connected to the front-end of the receiver. In its simplest form only two aerials are used, and switching from one to the other occurs whenever the signal level on the one in use falls sufficiently to activate the changeover switch.

The matter of threshold setting is worthy of mention because although it should clearly be low enough to prevent unnecessary switching, a setting which is optimum in one area is not necessarily the best when the vehicle has moved some distance away. Figure 3(b) shows a modified system which incorporates a variable threshold derived from the mean signal level in the vicinity of the vehicle[17] and this takes some account of the slow fading encountered by the vehicle as it moves. The long-term average is computed over a period comparable with the time the vehicle takes to travel tens of wavelengths, and the setting of the attenuator determines how far below the long-term average the signal is allowed to fall before switching occurs. A practical form of switched diversity for f.m. mobile radio has been described[18] that also includes circuits to ensure that the receiver is always connected to the aerial with the stronger signal when the vehicle is stationary or moving very slowly. However, it is not directly compatible with present-generation receivers.



(a) Basic form of scanning diversity.



(b) Scanning diversity system with variable threshold.

Fig. 3.

There is a modification of switched diversity which allows the mobile to carry only one receiving aerial. It involves using the mobile transmitter to inform the base station that the vehicle is entering a fade, and is known as feedback diversity.[19] In this system the spaced aerials are at the base station, and whenever the signal at the mobile falls below the threshold, the mobile transmitter sends a message (in the form of a tone-burst) back to the base station which then switches to the other aerial. Due to the inherent delay in this system, its performance is marginally inferior.

4.1.2 *Combining methods using perturbation techniques*

A number of single-receiver systems which have continuous rather than switched inputs have been devised, and usually form combiners of the equal gain type. In a two-branch combiner, perhaps the simplest method is to place a phase shifter in one of the aerial leads, and to adjust it in a 'hill-climbing' manner using a suitable d.c. voltage, e.g. the receiver a.g.c. line, as an indication of the input signal level. The disadvantages are that the receiver time-constants may be such that the system cannot follow the fast fades at higher frequencies, and

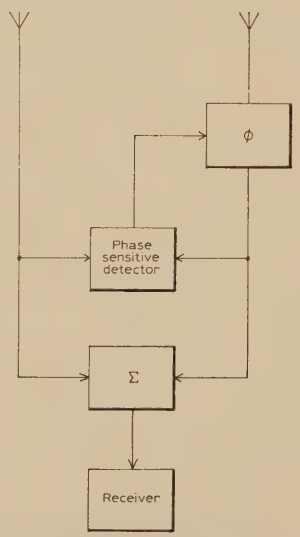


Fig. 4. Equal gain combiner with co-phasing control information derived from a direct phase comparison.

there is no simple method of extending the system to three or more branches.

A more flexible technique is to adjust the phase-shifter by means of a control voltage derived from the relative phase between the r.f. signals, as illustrated in Fig. 4, and in a.m. systems a convenient scheme for detecting whether a phase lag or phase lead condition exists has been described by Lewin.[20] A low-frequency sinusoidal oscillator drives a small-deviation phase-perturbing network which is connected in series with the phase-shifter, and as shown in Fig. 5, this produces amplitude perturbation of the sum signal. The phase of this perturbation changes by 180° as the perturbed signal changes from lagging to leading the sum signal. When the r.f. signals are co-phased only a small second harmonic is present, and a 'sense-of-correction' indication can therefore be obtained by low-frequency phase detection of the amplitude perturbations detected by the receiver with the original perturbing oscillator. This procedure produces a positive or negative d.c. control signal that is used to determine the direction in which the phase-shifter must be adjusted in order to approach the optimum position. The method is readily extended to N branches, provided $(N-1)$ control circuits are used each with its own perturbing frequency. For f.m. receivers a dual technique has been proposed in which small amplitude perturbations are applied to the r.f. signals.[21] The resulting phase perturbations in the sum signal can be detected by the receiver and similar signal

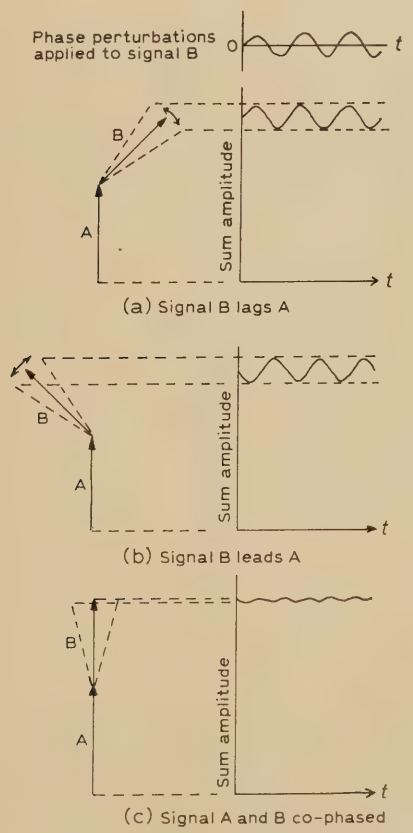


Fig. 5. Method of detecting phase relationship using phase perturbations.

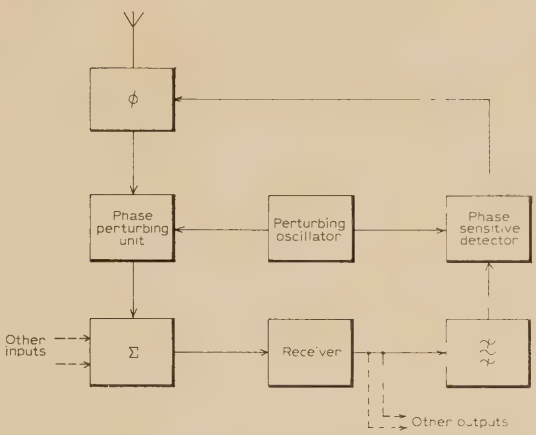


Fig. 6. Predetection combiner using phase perturbations to derive control signals for co-phasing.

processing can be used to provide the control information. Various practical embodiments of the technique have been described for a.m. systems[22–24] and a typical system is shown in Fig. 6.

The major disadvantage in the practical systems is that since it is not easy to build an analogue 360° phase shifter for insertion in the r.f. path, it is usual to use a unit that is quantized into a number of steps. However, the association of a quantized phase shifter with a 'sense-of-correction' detector leads to a situation in which the phase-shifters oscillate about their optimum position. This is due to the inability of such systems to detect the optimum position, the polarity of the control signal being reversed only after that position has been passed. This oscillation can be eliminated by using a true phase measurement scheme, and a new compatible direct-reading method has been proposed.[25] In this method, the r.f. signals are single-sideband modulated without carrier suppression by different low-frequency signals. The phases of the introduced sidebands are transposed on to the sum signal, and thus the phase of the detected modulation differs from that applied by exactly the phase angle between the appropriate r.f. signal and the sum. It is thus possible to generate control signals which can be used to set the phase shifters. A block diagram of such a system is shown in Fig. 7, and due to the nature of the s.s.b. signal, a f.m. or a.m. receiver can be used.

There are several ways in which the co-phased signals can be added together. An active summing unit can be used, but unless very carefully designed, it is likely to cause a degradation in receiver intermodulation performance. A simple hybrid is commonly used, but this has the disadvantage that some power is always dissipated at the difference port except in the special case of equal-amplitude input signals. One possible arrangement using hybrids to provide total power transfer[26] is shown in Fig. 8. Phase-shifter A is adjusted to give quadrature signals at the inputs of the first hybrid and so it provides equal-amplitude signals at its output ports. Phase-shifter B is than adjusted to co-phase these signals so that the second hybrid produces an output only at its sum port. However, in the mobile radio environment,

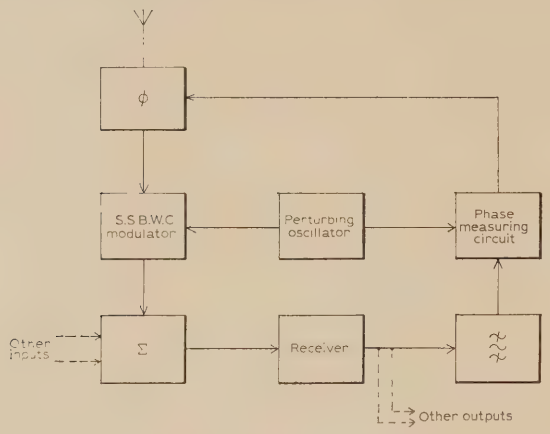


Fig. 7. Predetection combiner using phase measurements to derive control signals for co-phasing.

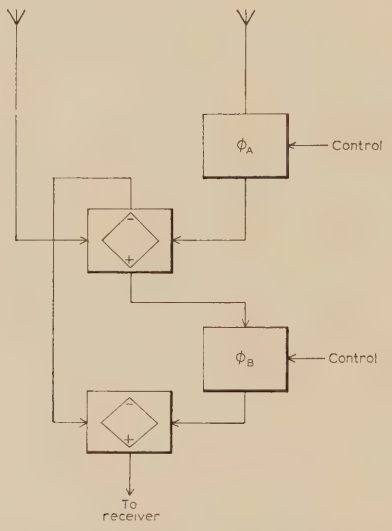


Fig. 8. A total power combiner (after Sidwell).

the improvement in performance compared with that of a single hybrid is unlikely to justify the cost and complexity involved in implementing such a system.

Systems of this kind are mainly limited by the maximum rate of phase compensation attainable. This is determined by the number of input branches and the total processing bandwidth available for the perturbing signals, since these factors determine the response times of the filters used to isolate these signals after detection. The perturbing frequencies must be such that the control information passes through the receiver without causing interference to the wanted information sidebands.

4.1.3 *Phase-sweeping method*

Another technique for use with a single standard receiver employs a method of continuously sweeping the phase in one of the signal paths. This has been considered, both theoretically and practically, by a number of authors.[27–29]

The method of operation is relatively simple and can be explained by considering the part of Fig. 9 prior to the receiver. If the phase-shifter continuously changes its value, between 0 and 2π radians, there are instants in time when the two signals come into phase and a peak occurs. If the rate at which the 2π phase excursion is repeated is at least twice the highest modulation frequency expected in the received signal, then peaks occur at a rate to satisfy the sampling theorem. By using a peak detector and a suitable filter, demodulation of a.m.-signals is possible giving the improvement expected from a diversity technique.

The operation of the system can be considered from another view-point.[27] The two spaced aerials form a two-element array which has a multi-lobed directional pattern. This directional pattern is electronically scanned by the phase-shifter and a 2π radian change causes it to move round in angle by one lobe spacing. Therefore, no matter where the transmitter is located, a lobe of the receiving pattern will scan across it.

The way in which the phase-shifter sweeps out the 2π radians is of importance to avoid serious spectrum spreading and hence simplify signal retrieval while maintaining s.n.r. It appears that the best choice is to cause the phase to change linearly with time. This can be achieved by using a repetitive saw-tooth phase modulation, and is equivalent to frequency translating the whole of the spectrum passing through the phase-shifter by an amount $1/T$, where T is the repetition period. An experimental system as shown in Fig. 9 has been evaluated, using a staircase approximation to give the required phase shift.[28]

The majority of work on the technique has been directed towards a.m. systems although, in theory, it appears applicable to f.m. systems.[30]

The method can also be applied to higher orders of diversity but each additional phase-shifter has then to be swept at a progressively higher rate in proportion to the order. In this case it seems easier to realize the system in a form described in the next Section.

4.2 Receivers with Multiple front-ends

The increase in losses, and the degradation in noise figure and intermodulation performance of receivers, which is caused by the use of units such as r.f. phase-shifters and perturbation networks prior to the r.f. amplifier can be overcome by receivers designed along conventional lines but having more than one front-end. This approach may also render feasible an otherwise unattractive solution, or simplify previously considered alternatives.

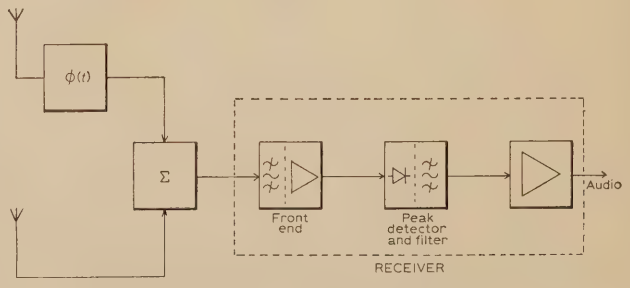


Fig. 9. Basic phase-sweeping diversity receiver.

With this type of receiver, for example, a direct detection of the relative phase between the signals is possible at an intermediate frequency, provided this frequency is sufficiently low. Each diversity branch then requires its own r.f. amplifier and mixer, but one local oscillator, with various outputs whose phases can be independently controlled, is sufficient. The outputs of the phase comparators are used to control the phases of the local oscillator outputs before mixing, and co-phasing of the signals takes place at the intermediate frequency.[31]

The perturbation methods can also be implemented in a similar way. The perturbations themselves can be introduced either in the signal path after the r.f. amplifiers, or added to the local oscillator outputs. However, if the perturbation contains amplitude modulation components, true multipliers must be used as mixers.

The phase-sweeping method becomes particularly attractive in association with a multiple front-end receiver. Since the linear phase sweep is equivalent to a frequency shift, the desired effect can be achieved by connecting the aerials to front-ends which have local oscillators at different frequencies. To obtain good adjacent channel rejection, a suitably-tuned i.f. amplifier is used in each branch, and the signals are summed before demodulation and filtering. This system has been proposed for h.f. communication[29, 32] and a block diagram is shown in Fig. 10. It is interesting to note that it is possible to apply a.g.c. around each individual i.f. amplifier and thereby produce a maximal-ratio diversity combiner.

4.3 Special Receivers

A whole class of predetection combiners can be derived from a circuit sometimes known as the 'heterodyne phase-stripper'. This circuit, shown in the block diagram of Fig. 11 has the property that the phase of the output signal is independent of the phase of the input. To illustrate the action of the circuit let us assume an input signal of the form

$$S_1(t) = A(t)\cos[\omega_c t+\phi(t)+\phi_0]+A_p\cos(\omega_p t+\phi_0)$$

in which the first term represents an amplitude and phase modulated carrier, and the second is a pilot tone at a

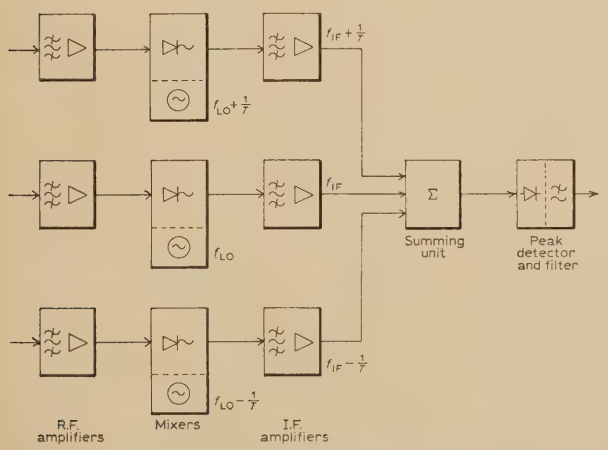


Fig. 10. Three-branch diversity receiver with continuous phase-sweeping produced by offset local oscillators.

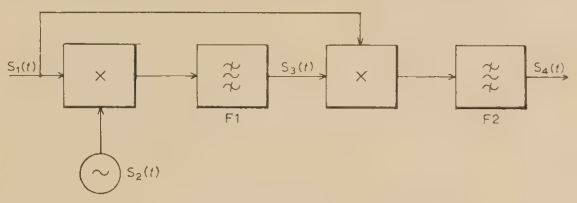


Fig. 11. The double-heterodyne phase-stripper.

frequency sufficiently close to the carrier that it is valid to assume that the propagation medium affects the phase of both in the same way. The signal is multiplied by a local oscillator signal

$$S_2(t) = B\cos(\omega_0 t+\theta)$$

at a frequency lower than that of the carrier, and the resultant signal is passed through a very narrow band-pass filter F1 which is centred at a frequency equal to the difference between the local oscillator and either the pilot-tone or the carrier. If the centre frequency corresponds to the latter case, F1 should be narrow enough to reject all modulation associated with the carrier. The output of F1 will then be of the form

$$S_3(t) = A_F\cos(\omega_F t-\theta+\phi_0)$$

with ω_F equal to either $(\omega_c-\omega_0)$ or $(\omega_p-\omega_0)$, and this is now multiplied by the fed-forward signal $S_1(t)$. Filter F2, which is wide enough to pass the modulation sidebands of the output, has a centre frequency given by the difference between the centre frequency of F1 and either the pilot-tone or the carrier. If the pilot-tone frequency is chosen to determine the centre frequencies of the filters then the output of the circuit is

$$S_4(t) = k\{A(t)\cos[(\omega_c-\omega_p+\omega_0)t+\phi(t)+\theta]+ +A_p\cos(\omega_0 t+\theta)\}$$

and if the carrier frequency is chosen, the output is

$$S_4(t) = k\{A(t)\cos[\omega_0 t+\phi(t)+\theta]+ +A_p\cos[(\omega_p-\omega_c+\omega_0)t+\theta]\}$$

It can be seen that in both cases the static input phase ϕ_0 has been cancelled at the output, the phase of the local oscillator has been acquired, and the modulation has been preserved.

There are various alternative choices which can be made for the local oscillator and filter frequencies in order to obtain this cancellation of ϕ_0, the output being always at the local oscillator frequency. For example, if the frequency of the local oscillator is higher than that of the carrier and $\omega_F = \omega_0-\omega_c$, then F2 is centred at $\omega_c+\omega_F$ to obtain cancellation, and the local oscillator frequency is regenerated at the output. However, in most practical embodiments of this technique it is usual to perform an initial frequency down-conversion, and then to use the circuit described with a local oscillator at another lower frequency. In this way phase-stripping and conversion to a second intermediate frequency are both accomplished at the same time.

Since the phase of the output signal is that of the local oscillator, applying the same local oscillator to the various branches of a diversity reception system will automatically co-phase the various signals provided that

the 'static' phases vary slowly, or in other words that the fading rate is slow compared with the bandwidth of filter F1. In this case the signals can be added after the second multiplier, with filter F2 following the summing unit, and a predetection combiner results. Figure 12 shows this arrangement with only two diversity branches fully drawn.

Systems using this principle can be broadly classified into two categories: systems with and without pilot-tones. The following sections describe different methods of implementation.

4.3.1 *Pilot-tone systems*

The idea of the 'phase-stripper' was originally applied to a diversity system that used a pilot-tone located in the middle of the baseband to compensate for phase changes associated with the information modulation.[33] The filters F1 in Fig. 12 selected a frequency determined by the pilot-tone. However, if the pilot-tone is located outside the baseband, and can be recovered by F1, the local oscillator is not needed since the recovered pilot-tone can be used in its place. In this case F2 can be a low-pass filter and its output is

$$S_4(t) = k\{A(t)\cos[(\omega_c-\omega_p)t+\phi(t)]+A_p\}$$

A block diagram of such a system[34] is shown in Fig. 13.

In other embodiments of this principle, illustrated in simplified form by the block diagram of Fig. 14, the filters F1 are eliminated altogether, and the remaining multipliers are replaced by either true squarers[35] or by devices whose characteristic exhibits a second-order non-linearity.[34] Filter F2 then selects the difference frequency $(\omega_c-\omega_p)$ which is subsequently demodulated.

4.3.2 *Systems without pilot-tone*

It has been pointed out [36] that the principle of the phase-stripper can be applied to signals which contain no pilot-tone, provided a carrier is present in the received signal, and this is also apparent from the equations at the beginning of Section 4.3. However, for the system to function correctly as a predetection combiner, the filters F1 must reject all the information sidebands and care must be taken to isolate the local oscillator from the output of the circuit.[37, 38] It can be shown that in this case the circuit of Fig. 12 is a maximal-ratio combiner but if the second set of multipliers are replaced by mixers it becomes an equal-gain combiner.

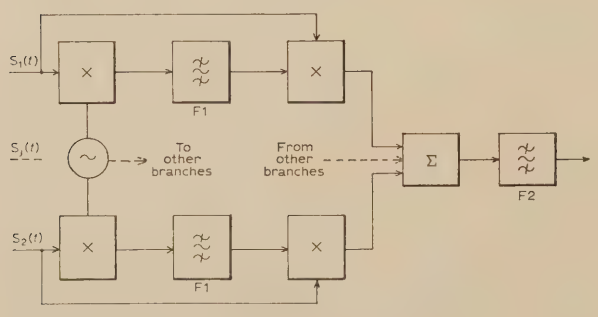


Fig. 12. Predetection combiner using the phase-stripper principle.

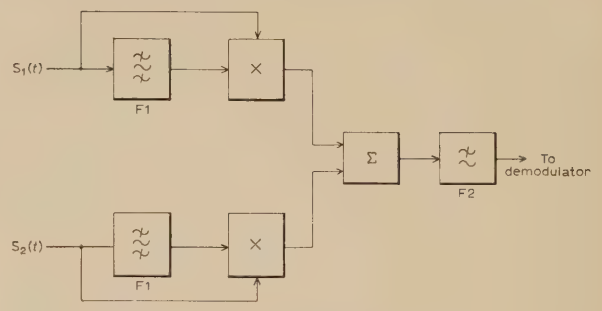


Fig. 13. Phase-stripping combiner using the transmitted pilot-tone in place of the local oscillator.

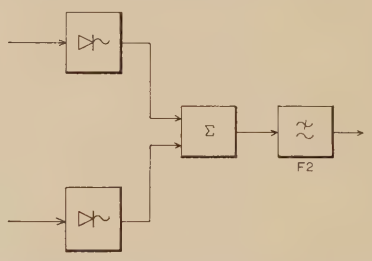


Fig. 14. Phase-stripping combiner using a transmitted pilot-tone with a non-linear device as mixer.

The fact that all the input signals are reduced to a common frequency and phase equal to those of the local oscillator points the way to an interesting solution[39, 40] which historically preceded those already mentioned. The combined output signal, suitably amplified, can be used as the local oscillator, forming a regenerative closed loop. Figure 15 shows such a system with outputs indicated for a.m. and f.m. demodulators. This solution has two main advantages over systems using a local oscillator. Firstly, good isolation between the local oscillator and the output is no longer necessary, and secondly, for f.m. signals the filters F1 although narrow-band, do not need to be very sharp. The latter advantage results from the presence of modulation at both inputs to the first multipliers, and since F1 selects the difference frequency, modulation components in the range of interest will cancel. A theoretical analysis of this type of combiner has recently been published.[41]

An alternative way of solving the problem of the gain of each loop being a function of the amplitude of its input signal is to use an a.g.c. amplifier[42] and this is illustrated in Fig. 16. As with the local oscillator system, the closed-loop approach can produce maximal ratio or equal-gain combining depending on whether multipliers or mixers are used prior to the summation point.

4.4 Energy-density Reception

Diversity reception systems so far considered have been designed to operate with any set of fading signals which are sufficiently uncorrelated. However, Pierce[2] has devised a technique for mobile radio which specifically includes a composite aerial. He observed that in simple fading fields the total electromagnetic energy density remains constant although the electric and magnetic field components both exhibit deep fades, and proposed the use of co-sited but separate electric- and

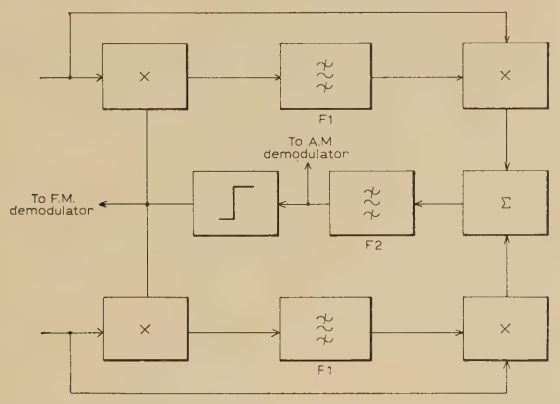


Fig. 15. Closed-loop phase-stripping combiner using limiter (Granlund receiver).

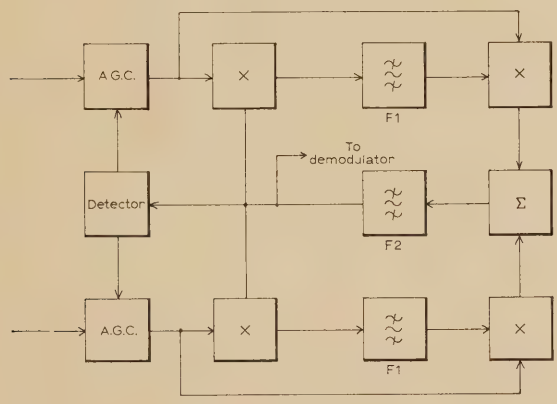


Fig. 16. Closed-loop phase-stripping combiner using automatic gain control (after Cease).

magnetic-field sensing aerials with their outputs combined so as to produce a signal proportional to the energy density $D = \frac{1}{2}[\varepsilon|E|^2+\mu|H|^2]$. A suitable aerial has been devised[43] and consists of two small mutually orthogonal semi-loops above a ground plane as shown in Fig. 17. The loops are taken to hybrid sum and difference networks, the sum ports giving outputs proportional to the electric field, and the difference ports outputs proportional to the resolved components of the magnetic field.

A problem arising with the use of this method is that the squaring process causes distortion with conventional modulation methods and it is clearly undesirable to resort to taking the square root of the receiver output. Since Clarke's model predicts that the electric and magnetic components of the field at any point are uncorrelated, thus making 'field-diversity' a possibility, a more promising approach would appear to be to use the composite aerial to provide the uncorrelated signals, and then to combine these signals using one of the methods described above. In this connexion other versions of the composite aerial have been proposed, in which the crossed loops are replaced by slots, and a separate vertical monopole is used.[44, 45] These aerials provide three outputs of comparable amplitude without the matching difficulties which arise from the use of loops. A signal proportional to the magnetic field can be obtained by combining the outputs of the two loops or slots via a $\pi/2$ phase shifter (since $H = H_x+jH_y$), and thus it would seem possible to construct a simple two-branch field-diversity system in this manner.

5 Discussion

Mobile radio in this country is an established system and therefore any changes have to be introduced by evolution rather than revolution. The capital investment in both base-station and mobile equipment is large and therefore the introduction of diversity techniques restricts the choice, in general, to methods compatible with the existing system.

The ideal advantages offered by diversity are that improved communication performance can be obtained without an increase in transmitter power or bandwidth. The ideal cannot be achieved with all the methods described, in that an increase in bandwidth is sometimes required and in other cases the full diversity gain cannot be achieved. However, the improvement that can be obtained, in practice, even with only a two-branch system, is of the order of 10 dB at the 99% reliability level. This is more easily found by using diversity, which only requires a moderate amount of equipment, than by increasing the transmitted power with the resulting increase in interference.

The usefulness of applying diversity depends very much upon environment, the reliability required of the mobile service, the format of the signals conveyed and other techniques which may be used to provide improved communication efficiency. Discussing these in turn, the environment may consist of geographical areas where screening of signals or multi-path exist. Also there may be good coverage in the region from a co-channel transmitter (the same frequency utilized by another user), or there may be other local sources of interference. Provided the wanted signal is slightly larger than the unwanted ones, the diversity systems exploit the strong-signal capture effect and the interference is reduced.[17] The reliability of the service is very dependent upon the user's requirements. Reliability is being used here in the communication sense rather than with reference to the equipment. For emergency services, near 100% reliability needs to be attained. For other services, holes in coverage might be tolerable but are only accepted with reluctance by the user. The other important factor is the type of message to be conveyed. For example, if speech

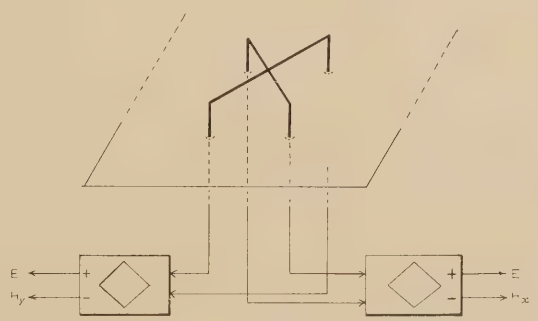


Fig. 17. Composite aerial with hybrids to resolve the components of the electromagnetic field (energy-density antenna).

is used, then short fades and flutter generally do not matter since there is sufficient redundancy in the language to cope. The redundancy may also be effectively increased by the use of standard phrases, careful choice of words, by repeating the message, or by requesting a repetition.

Some users require facsimile facilities, and others 'hard-copy' teleprinter type messages. These message formats are very susceptible to fades and diversity techniques, as described in this paper, appear well suited to reducing this problem. Obviously redundancy coding is a competitor, but this eats into the information bandwidth compared with diversity. However, in a number of cases it is not possible to use the ultimate channel spacing due to stability problems, and a wider bandwidth has to be provided. Therefore, although redundancy may well be the best choice, care is necessary since the fading-rate encountered in mobile radio is a function of vehicle speed.

Base station transmitter diversity[19, 46, 47] has been mentioned earlier and it offers certain advantages and disadvantages over mobile receiver diversity. There is obviously a strong argument for keeping the complexity at the base station whilst keeping the mobile units simple. However, since the diversity spacing is large, several aerial towers are necessary and so more land is needed. The cost of the structures, etc., will not be insignificant, but may compare favourably with the cost of modifying all the mobile units. For some users, it may be impossible to increase the area occupied by the base-station if, for example, they operate from the roof of a building.

One possible diversity technique which may be used at base-station transmitters is similar to the phase sweeping method described for the mobile receiver. The disadvantage is that it occupies more radiated bandwidth than a non-diversity channel. This increase in bandwidth, when using the same technique for diversity reception in the mobile is of no importance since it occurs only in the receiver circuits and not in the medium, and the mutual interference problem is not made worse.

Diversity applied to the mobile receiver has the advantage that the receiver is usable with any base-station and therefore wide area-coverage is possible without having a diversity system at every base-station. As to the choice of diversity to be used in the mobile, it is impossible to say that one method is superior to all others. In order to choose a system it is first necessary to ensure that it will work with the type of modulation in use. Secondly, there is the choice of using either an existing range of receivers, possibly with minor modifications, or adopting a method integrated into a new design of receiver. The final choice must be an economic one as, of course, is the choice between using diversity as opposed to either redundancy or (if allowed by the licensing authority) a straight increase in transmitter power.

6 Acknowledgment

Two of the authors (J.D.P. and M.H.) wish to thank the UK Science Research Council for a grant in support of work on diversity reception methods for mobile radio.

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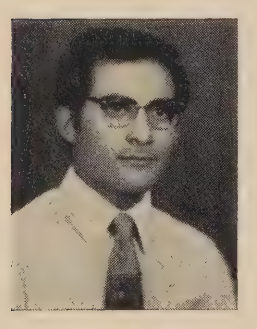
From 1962 to 1967 Dr. Hsiao was employed by Bell Telephone Laboratories in the Digital Systems Department, engaged in the research and application of superconductor devices. Since 1967 he has been with the Naval Research Laboratory, Radar Division and has specialized in the field of array antennas. His current interest is in the area of phased array radar systems.



Dr. S. I. Ghobrial received his B.Sc. in electrical engineering from the University of Khartoum in 1969. After a period of postgraduate work he was awarded a British Council Scholarship to study in England for higher degrees. He received the M.Sc. and Ph.D. in 1971 and 1973, both from the University of Bradford; his doctoral thesis was on cross-polarization in reflector antennas. Dr. Ghobrial has now returned to the University of Khartoum as a Lecturer in the Department of Electrical Engineering.

Dr. P. A. Ratliff graduated from the University of Birmingham in 1969 with a first-class honours degree in electronic engineering. He was awarded a BBC Research Scholarship and remained at the University to work on diversity reception techniques for mobile radio. His particular interest was a study of v.h.f. multipath fading in urban areas for which he gained his Ph.D. degree in 1973. Since leaving the University he has been with the BBC Research Department, Kingswood, Surrey.

Mr. J. D. Parsons (Member 1967) graduated at the University College of South Wales, Cardiff, in 1959 and later received an M.Sc. in electronics at King's College London. From 1959–62 he was a member of the Scientific Staff at GEC Applied Electronics Laboratories, Stanmore, and from 1962–69 he held teaching appointments at The Polytechnic, Regent Street, London, and the City of Birmingham Polytechnic. Since 1969 he has been with the Department of Electronic and Electrical Engineering, University of Birmingham and is currently leading a group engaged on research into various aspects of mobile communication. Mr. Parsons is immediate past chairman of the West Midland Section of the Institution.

Mr. Miguel Henze graduated in Electronic engineering at the Instituto Tecnologico de Aeronautica, Brazil, receiving the degrees of B.Sc. in 1962 and M.Sc. in 1970.

After graduation he spent eight months with Standard Electrica S.A., in Rio de Janeiro, and one year at the Technische Hochschule, Darmstadt, Germany, supported by the Rotary Foundation. Since 1964 he has held an appointment as Lecturer at the Instituto Tecnologico de Aeronautica.

Mr. Henze is now on leave of absence from his University, and has joined the mobile radio research group in the Department of Electronic and Electrical Engineering, University of Birmingham, where he is working on diversity reception techniques for u.h.f. mobile radio.

Mr. Michael J. Withers received a Dip. Tech. in engineering from Northampton College, London, (now the City University) in 1959, and an M.Sc. in information theory from the University of Birmingham in 1961.

From 1955 to 1962 he worked for Cossor Radar Ltd., Harlow, Essex, and from 1962 to 1972 as a Lecturer in the Electronic and Electrical Engineering Department of the University of Birmingham. In 1969–1970 he held the post of Visiting Professor of Telecommunications at the Instituto Tecnologico de Aeronautica, Sao Paulo, Brazil. At present he is with the British Aircraft Corporation Ltd., Stevenage, in the Radar Systems Study Group.

IERE News and Commentary

Rehabilitation of Disabled Engineers

A research programme is currently being undertaken at the Management Centre of the University of Bradford into the employment problems of professional people who become physically disabled during the course of their professional career. The immediate concern of the programme is with the rehabilitation needs of such people and the relevance of the present government rehabilitation services to them.

Within the United Kingdom rehabilitation services are more directly concerned with the semi-skilled, skilled and clerical worker. Even the occupational therapy within hospitals appears to be of more benefit to these workers, relative to their future employment, than to professionals. It is suggested that rehabilitation for the professional, regardless of profession, should reflect the need of the professional to practise professional thinking during the time he or she is unable to work. In other words, as well as the usual rehabilitation services there should also be provision for what may be termed 'educational rehabilitation'.

In order that the research may be more than an academic exercise the Management Centre wishes to learn the views, comments, and experiences of disabled professionals. To that end, therefore, readers, disabled or not, with any knowledge of rehabilitation (or, indeed, the lack of it) are urged to write to Mr. Melvyn Kettle, Production Management Research Unit, University of Bradford, Emm Lane, Bradford, Yorkshire BD9 4JL. Theri replies will, of course, be treated in strict confidence and will be of invaluable help.

Israel's Research Effort

In a recent speech at the Weizmann Institute of Science, Dr. Eliezer Tal, the Director of the National Council for Research and Development (NCRD), said that Israel directs 43% of its investments in research to defence, 30% to universities, 12% to industry, 10% to Government institutions and the remaining 3% to other bodies. He suggested that scientists now working for the defence establishment be allowed to carry out part of their work in civilian installations.

Dr. Tal said that Israel now spends 2·4% of its gross national product (GNP) on scientific research. Statistically, Israel has 23 persons per 10,000 engaged in research in the civilian and defence sectors, as compared with a figure of 25 per 10,000 in the United States, and the European average of 20 per 10,000.

New Chairman of the British Overseas Trade Board

Sir Frederick Catherwood has accepted the invitation of Mr. Peter Shore, Secretary of State for Trade, to become Chairman of the British Overseas Trade Board with immediate effect. He succeeds Lord Thorneycroft, the founder-Chairman, who has retired after the three-year period he undertook to serve.

Sir Frederick is currently Chairman of the British Institute of Management and a director of John Laing and Son Ltd. and of other companies. He was Director General of the National Economic Development Office from 1966–71.

Revised Fees for Patents and Designs

Rules have been published under which patent and design fees payable to the Patent Office will be increased from 24th May 1975. The increase will apply to all stages of processing applications for granting a patent or registering a design, and for subsequent renewals. But the application fee for a patent—by which inventors stake their initial claim—will remain at £1.

The new *patent* fees will be as follows:

For filing a complete specification: £48 (formerly £25).

For sealing a patent: £17 (formerly £9).

For renewal: these fees have been increased to £15 for the fifth year to £39 for the 16th and final year.

These fees were last increased in May 1974.

The new *design* fees will be:

For a single article: £16 (formerly £8·50).

For a set: £32 (formerly £17).

For a second period extension: £40 (formerly £21). (These fees were last increased in May 1974).

For a third period extension: £57 (last increased to £30 in June 1971).

The new rules are covered by the Patents (Amendment) Rules 1975, SI 1975 No. 371, and the Designs (Amendment) Rules 1975, SI 1975 No. 372. Copies are available from HMSO, price 12p net in each case.

New Eye Protection Regulations

The Protection of Eyes Regulations 1974* came into operation on April 10th last. The Regulations were made under the Factories Act 1961 and replace the previous Regulations made in 1938. The new Regulations are much wider in scope, and greatly increase the number of people protected by covering those employed in specified processes on construction sites as well as in factories. Not only people actually working in these processes will be covered, but also, in certain cases, those whose eyes are at risk from these processes even though not directly employed in them.

Eye protectors must be issued on a personal basis, except for people only occasionally employed. Every protector has to meet the specification approved by the Chief Inspector of Factories and has to be suitable for the person using it.

The Health and Safety Executive are currently preparing a free, explanatory leaflet giving guidance to employers and employees on the new Regulations. Copies are available from District Offices of H.M. Factory Inspectorate or from the Health and Safety Executive, Baynards House, 1 Chepstow Place, London W2 4TF. (Tel. 01-229 3456, Ext 688)

* Statutory Instrument 1974 No. 1681 HMSO. Price 14p plus postage. Also Statutory Instrument 1975 No. 303 HMSO. Price 4p plus postage.

Dr. von Braun elected an Honorary Fellow

As the latest member of the Honorary Fellows' "Club", Dr. Wernher von Braun signs the roll watched by four of the ten living Honorary Fellows. Left to right, Professor H. M. Barlow, Earl Mountbatten of Burma, Mr. W. E. Miller and Mr. L. H. Bedford.

Over 50 members of the Institution, including six Institution Presidents, members of Council, and members of Committees, came to Bedford Square on 27th May to welcome Dr. Wernher von Braun when he was awarded his scroll of Honorary Fellowship and signed the roll of Honorary Fellows.

Introducing the new Honorary Fellow, the President, Sir Ieuan Maddock, paid tribute to Dr. von Braun's work in developing satellite launching vehicles, thus making possible the great strides in communications during the past decade, notably the INTELSAT system.

In his reply Dr. von Braun expressed his great pleasure in the honour which the Institution had bestowed on him. He believed that one of the most significant applications of communications satellites was shortly to be put into operation when a broadcasting satellite which for the past few months had been in geo-stationary orbit over the United States to give television coverage to mountainous or remote regions would be moved to a similar orbit over India. It would then be used to provide educational programmes of all kinds to remote villages which could never hope to be covered by a system of conventional transmitters.

An especial welcome to Dr. von Braun to the ranks of Honorary Fellows was given by Lord Mountbatten who took up the great potential of communication satellites and also referred to his recent visit to the Soviet Union where he had met several astronauts.

Following the brief presentation ceremony Dr. von Braun signed the roll which carries the following citation:

'Doctor Werner von Braun has been a pioneer of rocket propulsion for over forty years. He was educated at the University of Berlin and was concerned with experiments with liquid-filled rocket engines as early as 1930. From 1945, when he went to America, until his retirement as Deputy Associate Administrator of the National Aeronautics and Space Administration in 1972, he was closely associated with the development of guided missiles and satellite launching vehicles. Doctor von Braun has played an outstanding part in making possible the exploration of space by both manned and unmanned satellites, and by these means has made an inestimable contribution to the progress of twentieth century scientific discovery.

'This Testimony is a tribute to his notable contributions to science and engineering in most of which electronic instrumentation and radio communication have been an essential element.'

Dr. Von Braun gave the 8th Clerk Maxwell Memorial Lecture in March 1974 taking as his subject 'Our space programme after *Apollo*'—see June 1974 Journal.

President of the Institution Sir Ieuan Maddock recalling the reasons for the Institution electing Dr. von Braun to Honorary Fellowship. Also in the picture are Lord Mountbatten and Mr. G. D. Clifford, Director and Secretary.

Members' Appointments

BIRTHDAY HONOURS 1975

The Council has congratulated the following members whose names appear in Her Majesty's Birthday Honours List:

MOST EXCELLENT ORDER OF THE BRITISH EMPIRE

To be promoted to Ordinary Commander of the Military Division (C.B.E.)

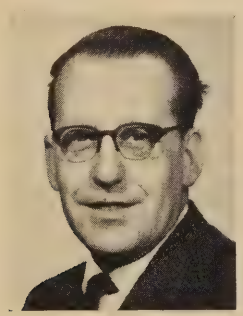
Commodore Sydney Robert Hack, O.B.E., R.N. (Member 1965, Associate 1947). H.Q. Allied Forces, Southern Europe.

To be appointed an Ordinary Member of the Civil Division (M.B.E.)

Roland Arthur Whiting (Associate Member 1973, Associate 1959). Telecommunications Technical Officer, Diplomatic Wireless Service, East Mediterranean Relay Station, Cyprus.

CORPORATE MEMBERS

Mr. A. E. Crawford (Fellow 1960, Member 1956) has become a full-time Director responsible for development with DDS Engineering Co. Ltd., Basingstoke, a company he formed some time ago. He will be mainly concerned with applications of ultrasonic devices in biological engineering. Mr. Crawford was with H. Tinsley & Co. Ltd. as manager of an agro-physics group from 1972 to this year. Following



war-time development work on radar he has worked on ultrasonics equipment and applications for more than 25 years, successively with Mullard, Redifon, Brush Crystal Company, Elliott Bros., and Radyne. He was an active member of the Southern Section Committee, serving as chairman during its early years, and he was also a member of the Technical Committee and of the Electro-Acoustics Group Committee. For several years he represented the Institution on BSI Technical Committees on Piezoelectric Crystals and Mechanical Standardization of Semiconductor Devices. Mr. Crawford has presented several papers at Institution meetings.

Mr. G. Poray, Dipl.Ing. (Fellow 1965) has been appointed Engineering Manager of Southern Cross TV (Pty) at a new monochrome receiver factory in Pietersburg, Transvaal, South Africa. Mr. Poray was formerly with Rediffusion Engineering Ltd., Kingston-upon-Thames, which he joined in 1953.

Mr. R. E. J. Bailey (Member 1969, Graduate 1962), who was previously Quality Control Manager and Chief Inspector with Chubb Alarms Ltd., has been promoted to the post of Works Manager at their London Office.

Mr. A. Bintcliffe (Member 1970) is now an Engineer with the Construction Division of the Department of Posts and Telegraphs at Port Moresby, Papua New Guinea. He was formerly Project Manager with Criscroft Ltd,. Billericay, Essex.

Mr. W. R. Cameron (Member 1966) has been appointed 2nd Engineer (Controls and Instrumentation) Generation Construction with the South of Scotland Electricity Board. He was previously Chief Production Engineer with Fabri-Tek Computer Components.

Mr. P. J. Carrington (Member 1974, Graduate 1971), who was previously Project Engineer for Test and Production Aids Ltd., Letchworth, is now a Microwave Applications Engineer, with Marconi Instruments, Sanders Division, Stevenage, Hertford.

Mr. P. R. Champion (Graduate 1968, Member 1972), formerly a Senior Engineer in GEC-Elliott Traffic Automation, is now a Professional Officer B in Traffic Development Operations, Signals Section, Greater London Council.

Flt. Lt. F. C. East, RAF (Member 1971, Graduate 1965), who was previously Officer Commanding Ground Radio Flight RAF Luqa, Malta, is being transferred to RAF Henlow, as Officer Commanding Ground Radio Installation Control Flight, Radio Engineering Unit.

Mr. P. J. Edwardson (Member 1972, Graduate 1967) has joined Unilab, Blackburn, as Works Manager. He was formerly Group Leader Electrical Engineering, with Thorn Colour Tubes, Skelmersdale.

Mr. D. H. Faulkner (Member 1973, Graduate 1968) is now Service Manager at Cambridge Scientific Instruments Ltd., Cambridge. He was previously a Project Leader with Marconi-Elliott Avionic Systems, Rochester.

Mr. C. P. Fowler (Member 1972, Graduate 1969) is now Manager, Foreign Trade, with Grindlays Bank Limited, London. He was formerly Senior Production Engineer with Pye Telecommunications Ltd., and recently completed a course for a Master's degree in Business Administration at Cranfield Institute of Technology.

Mr. A. E. Fyfe (Member 1971, Graduate 1969), who was until recently Manager (Engineering) with the West Coast of America Telegraph Co., in Lima, Peru, is now Manager of the Compañía Andina Tecnica S.A. at Lima.

Mr. A. M. Gall (Member 1973, Graduate 1967), who was formerly Senior Sales Engineer with Cossor Electronics Ltd., is now Quality Control Manager, ITT Consumer Products, Kearsley, Lancs.

Mr. G. Y. Gove (Member 1973) has been promoted to Professional and Technology Officer I, and is now at the Royal Naval Armament Depot, Gosport, Hants. He was previously a Professional and Technology Officer II attached to the Admiralty Underwater Weapons Establishment.

Mr. B. S. Heald (Member 1964) has been appointed Lecturer Grade A at the Mount Lawley Technical College, Mount Lawley, Western Australia. He was previously Tracking Systems Supervising Engineer, Carnarvon Tracking Station, Western Australia.

Mr. R. M. Hughes (Member 1966, Graduate 1961) has been appointed Deputy Director of Telecommunications at the Home Office, Central Communications Establishment, Harrow, Middlesex.

Mr. R. N. Jones (Member 1970, Graduate 1963), who was Senior Supervising Engineer, Engineering Services, Varian Techtron, Springvale, Victoria, Australia, is now Project Development Manager of the Company's Atomic Absorption Products division.

Mr. R. K. Loukes (Member 1973, Graduate 1966) has taken up the post of Communications Specialist at the Bahamas Oil Refining Company after fourteen years in Pye Telecommunications Ltd., Cambridge, latterly as a Senior Commissioning Engineer.

Mr. P. J. W. Noble (Member 1966, Graduate 1962), who was Managing Director of Integrated Photomatrix Ltd., Dorchester, for six years has joined Tekflo Ltd., Weymouth as Chief Executive and Director.

Mr. A. J. Payne (Member 1973, Graduate 1966), who was formerly Senior Engineer, Communications Terminal Development with I.C.L. at Stevenage, has been appointed Senior Engineer—Test Equipment, with Hawker Siddeley Dynamics, Stevenage.

Mr. J. Pemberton (Member 1970, Graduate 1965) has been appointed Head of Maintenance and Installation Division, Post Office Telecommunications, Swansea and South-West Wales Telephone Area.

Mr. I. G. Pugh (Member 1971), who was previously a Senior Project Engineer with Fischer & Porter, Toronto, has now taken up a position as a Control Engineer with the Ontario Hydro Power Corporation, Toronto.

Mr. K. Rajapaske (Member 1972) has been appointed as an Engineer with Bell-Northern Research Centre, Ottawa. He was previously with the Ceylon Posts and Telegraphs Department as a Superintendent Telecommunications Engineer.

Major-General H. E. Roper, B.Sc.(Eng.) (Member 1970, Associate Member 1953) has been appointed Assistant Chief of the General Staff (Operational Requirements), Ministry of Defence, Whitehall, London. He was formerly Chief Signal Officer HQ BAOR.

Mr. H. A. Warren (Member 1974, Graduate 1971), who was previously a Senior Engineer with EMI Electronics, Feltham, has been appointed Senior Engineer, Marconi Space and Defence Systems, Frimley, Camberley, Surrey.

Squadron Leader T. Winchcombe, M.B.E., RAF (Member 1969, Graduate 1956) has been appointed to the staff of the Director of Training (Ground) (RAF) at the Ministry of Defence in London. He was previously Officer Commanding Radar Squadron at No. 1 Radio School, RAF Locking.

Mr. E. E. Wiseman (Member 1972, Graduate 1961) has been promoted Senior Lecturer responsible for Student Welfare and Careers, Carshalton College of Further Education, Carshalton, Surrey.

Mr. L. W. B. Worrall (Member 1971, Graduate 1968), who has been Manager for Special Projects at Foxboro Yoxall Ltd., Redhill, Surrey, has now been made Manager for Systems Production Control.

Mr. F. W. Wright (Member 1960, Associate 1956), following a year as Manager of Special Projects for TAI Inc., Tehran, who are telecommunications consulting engineers, has been promoted to the position of Manager, Project Operations, Iran.

Mr. S. A. H. Zaidi (Member 1974) has been appointed Senior Engineer, Hermes Electronics, Dartmouth, Canada. He was formerly a Section Leader in the Circuit Laboratory, with Decca Radio and TV Ltd., Leicester.

NON-CORPORATE MEMBERS

Flg. Off. D. M. H. Brown, RAF (Graduate 1968) has been appointed Officer Commanding Instrument and Electrical Flight, RAF Leuchars, Fife. He was previously working on Automatic Test Equipment.

Staff Sergeant K. D. Brown (Graduate 1970) has been appointed Troop Artificer (SAGW) with 36 Heavy Aid Detachment Regimental Workshops, REME. He was previously an Instructor in SAGW Radar at the School of Electronics Engineering, Arborfield.

Mr. T. H. Clark (Graduate 1969), who was previously an Electronic Engineer in the Development Group at G.E.C. (Electronics) Ltd., Portsmouth, has been appointed Senior Quality Engineer with Singer U.K. Ltd., Lancing, Sussex.

Mr. J. D. Francis (Graduate 1969) has been appointed Service Engineer with Ferranti at Wythenshawe, Manchester. He was previously with Marconi Space and Defence Systems at Hillend.

Mr. J. Henshaw (Graduate 1970) has taken up a position as Section Head of Quality Engineering, Standard Telephones & Cables Ltd., Submarine Systems Division, at the Western Dock in Southampton. He was formerly Principal Engineer, Quality Planning, Plessey Co. Ltd., Transmission Division, at Beeston in Nottinghamshire.

Mr. D. R. Mason (Graduate 1971) has been appointed Industrial Engineer with Tannoy Products Ltd., West Norwood, London. He was previously Planning Engineer with Burroughs Machines Ltd., at Croydon.

Mr. C. N. Umoh (Graduate 1969), who since November 1974 has been an Area Engineer in the Federal Ministry of Communications of Nigeria, has been transferred from Zaria to Kano as the Senior Telecommunications Engineer for the Kano State of Nigeria.

Mr. J. W. Carlton (Associate 1961), Technical Manager for the UK and Western Europe with Pye Telecommunications, has been elected Chairman of the Mobile Radio Committee of the Electronic Engineering Association. Mr. Carlton joined Pye in 1953 after serving in the RAF Signals.

Mr. M. S. Edirisinghe (Associate 1972) has been appointed Electronic Engineer with Elcome International at Dubai. He was formerly a Lieutenant (L) in the Sri Lanka Navy at the Naval Dockyard at Trincomalee.

Obituary

The Council has learned with regret of the deaths of the following members:

Christopher James Paterson Todd (Member 1971, Graduate 1965) died on 25th March 1975, as a result of a car accident in Riyadh, Saudi Arabia. He was 50 years old and leaves a widow and three daughters.

Chris Todd was born and educated in East Grinstead and during the war served as a pilot in the Fleet Air Arm. He joined Cable & Wireless Ltd. following demobilization, remaining with the company for the remainder of his life. His first overseas appointments between 1949 and 1958 were in Cyprus and Colombo and from 1959 to 1964 he was in the Engineering Chief's Department at the Company's Head Office in London where he was associated for some of the time with project planning. During these years he studied for the Higher National Certificate at the Borough Polytechnic, passing it with endorsements in 1964.

In 1965 Mr. Todd was seconded to the External Telecommunications Service of the Posts and Telegraphs Department in Ghana as a Radio Engineer responsible for commercial external h.f. radio communications. In 1966–67 he was at Kampala, Uganda, as a Project Engineer and took charge of the development, including planning and construction, of a central telegraph office and a common site h.f. radio station. Following a course on tropospheric scatter communications he went to Bahrein as Operations Engineer where he remained until 1973. During this period he was for some two years Secretary to the Frequency Assignment Committee (Gulf) and subsequently Engineer-in-Charge of the Sitra Road Receiving Station.

In September 1973 Mr. Todd was posted to Riyadh, Saudi Arabia, as Chief Engineer of the 1,200 kW medium-wave broadcasting station operated by Cable & Wireless.

Arthur Woffenden (Member 1936, Associate 1932) died in December aged 70 years.

Born and educated in Yorkshire, Mr. Woffenden was apprenticed to a Leeds firm of electrical engineers from 1918 to 1921 and during the next 18 years worked for several radio companies in the Leeds area. In 1939 he jointly founded the company of A. C. Farnell Ltd., to which he returned in 1944 as technical director following war service. This company was built up under his direction as an area distributor for leading instrument companies and at the date of his retirement in 1968 had established several subsidiaries.

Peter Arthur Owen Northey (Member 1943) died in Jersey on 5th December 1974 aged 68 years.

Born in Scotland and educated at Malvern and the Royal Military College, Sandhurst, Peter Northey was initially a Battalion and Brigade Signals Officer. In 1939 he transferred to Anti-Aircraft Command where he became eventually Chief Instructor (Fire Control) with the rank of Lieutenant-Colonel. Following a distinguished war-time career Col. Northey held appointments in the radio industry, first with Romac Radio Corporation as General Works Manager, and later as Chairman of Fidelity Sound Equipment Ltd. In 1954 he moved to Jersey.

From 1943 to 1945 he served on the Council of the Institution.

Conference on 'Hybrid Microelectronics'

Organized by THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS in collaboration with The International Society for Hybrid Microelectronics with the association of The Institution of Electrical Engineers, The Institute of Physics and The Institute of Electrical and Electronics Engineers.

University of Technology, Loughborough—9 to 11 September 1975

Provisional Programme

Tuesday, 9 September 1975

Welcome by PROFESSOR D. S CAMPBELL,
Chairman of the Conference Organizing Committee

Opening address by MR. D. BOSWELL
'Applications of Hybrid Circuitry—A Review'

NEW MATERIALS AND TECHNIQUES

'Theories of conduction in thick film resistors'
By DR. R. M. HILL

'Surface area, structure and composition of debased alumina substrates'
By M. V. COLEMAN and G. E. GURNETT (*S.T.L.*)

'Substrate bowing in thick film multilayered circuits'
By J. SAVAGE and N. DAVEY (*A.W.R.E.*)

'High tensile strength thick-film silver-palladium metallizations'
By T. H. LEMON (*Johnson, Matthey & Co.*)

'An air fireable base metal conductor for optoelectronics'
By DR. F. K. PATTERSON, DR. A. H. MONES and R. J. BACHER (*Dupont, U.S.A.*)

'Recent advances in platinum-silver thick film conductors'
By S. J. STEIN, C. HUANG, L. CANG and G. SCHULTZ (*Electro-Science Laboratories, U.S.A.*)

'Commercial materials for thick film production with data on laser trimming'
By A. W. KOSZYKOWSKI

APPLICATIONS

'A simple hybrid thick film band pass filter'
By D. P. HEYWOOD (*R.A.E.*)

'A hybrid thin-film multichannel biotelemetry transmitter'
By DR. J. H. FILSHIE and I. J. MCGEE (*Agricultural Research Council*)

'A thick film humidity sensor'
By N. D. CHANNON (*Brighton Polytechnic*) and DR. P. G. BARNWELL (*Barnwell Components*)

Wednesday, 10 September 1975

APPLICATIONS (*continued*)

'High frequency characteristics of meandering line-resistors with regards to the design of thin-film circuits'
By H. GRUNDNER and H. FECHNER (*Munich University*)

'A thick film wide band amplifier'
By D. R. HETHERINGTON (*Newmarket Transistors Ltd.*)

'A fast thick film amplifier'
By DR. J. ROBERTSON and B. ANDERSON (*Edinburgh University*)

'Thick film directional coupler design—A comparison of theories'
By DR. P. L. BAINBRIDGE and R. J. ROBERTSON (*Dundee College of Technology*)

'Comparative investigation of thick film and thin film components and microelectronics up to 16GHz'
By W. FUNK and W. SCHILZ (*Philips, Hamburg*)

'Hybrid displays using gallium phosphide l.e.d.'s'
By R. O'ROURKE (*Allen Clarke Research Centre*)

'Screen printable transparent electrodes'
By B. WALTON and DR. H. DE LACY (*E.R.A.*)

'Linear opto-electronic circuits using thin films'
By DR. J. T. LAW and J. M. MORRISSON (*Ferranti*)

EDUCATION AND TRAINING

Open forum with the following three papers presented as initial contributions to the discussion:

'The hybrid microelectronics explosion in Finland'
By E. JARVINEN (*University of Oulu*)

'Technological teaching of hybrid microelectronics'
By Y. LEROY, M. DESCAMPS and M. VERNET (*University of Lille*)

'Thick film research in a University environment'
By PROFESSOR D. S. CAMPBELL and P. L. MORAN (*University of Loughborough*)

MANUFACTURING TECHNOLOGY

'A technology for high speed computer systems'
DR. S. HOLLOCK (*Allen Clark Research Centre*), DR. D. J. KINNMENT (*Manchester University*) and N. V. MARTON (*Burroughs*)

'Automatic manufacture of custom hybrid microelectronic circuits'
By R. F. RUSSELL and R. THOMPSON (*ITT*)

'Stability and forward diode voltage characteristics of conductive epoxy resin bonded devices'
By I. GENNER (*Newmarket Transistors*)

Thursday, 11 September 1975

MANUFACTURING TECHNOLOGY (*continued*)

'A range of automatic machines for thin film circuit manufacture'
By J. LANTIAIRES and YOUNG

'Trimming of thin-film resistors by spark machining'
By DR. J. T. LAW (*Ferranti*)

RELIABILITY AND TESTING

'Microcircuit thermal design tables and computer program for two-dimensional layouts'
By P. G. HAMBLING and D. J. DEAN (*A.W.R.E.*)

'Evaluation of the noise index in laser trimmed thick film resistors'
By D. A. BIANCHI and A. CATTANEO (*Magneti Marelli*)

'Thick film focus control potentiometer'
By DR. P. L. BAINBRIDGE (*Dundee College of Technology*) and J. A. BLACKERY (*Littlefuse*)

'The assessment of thick film resistor performance by high voltage pulsing'
By DR. H. DE LACY (*E.R.A.*)

'A technique for the testing of unassembled multilayer hybrid substrates'
By P. L. MORAN (*University of Technology, Loughborough*)

Technical News

UK Waste Materials Exchange

Following representations by a group of industrial environmental specialists representing UK chemical companies the Department of Industry has decided to establish a UK Waste Materials Exchange. This will be concerned with waste materials originating from manufacturing processes in general but excluding wastes from domestic sources, and those scrap metals, second-hand equipment and related materials for which adequate commercial markets are already in existence. Such materials could for example be referred to the National Industrial Materials Recovery Association.

A Waste Materials Exchange should make a significant contribution to the conservation of resources which is now even more necessary as a result of increasing energy and raw materials costs and shortages of oil based derivatives. It should also assist in removing certain polluting material from the environment and in reducing the costs of achieving acceptable disposal under the provisions of the Deposit of Poisonous Waste Act, 1972, and in accordance with the Control of Pollution Act, 1974.

The Exchange will be operated initially for two years by the Warren Spring Laboratory of the Department of Industry and will be free to participants. A central registry will be maintained on the notifications of wastes for disposal and materials required, and a bulletin will be published at quarterly intervals listing the materials without disclosing company names. Enquiries for a particular material will be forwarded to the company originating the waste so that they may make their own commercial arrangements and full confidentiality will be maintained. Firms disposing of material through the help of the Exchange will be asked to inform the registry in order to assist in monitoring performance.

The bulletin may be obtained from UK Waste Materials Exchange, PO Box 51, Stevenage, Herts SG1 2DT (Telephone: Stevenage (0438) 3388).

Monitoring and Control of Proton Synchrotron at the Rutherford Laboratory

The *Nimrod* Physics Development Group at the Science Research Council's Rutherford Laboratory at Chilton, near Didcot, Oxfordshire, has taken delivery of a GEC 4080 computer system which will update the present computer provision on the synchrotron and provide more powerful real-time computing aids. The *Nimrod* 7 GeV proton synchrotron is used by high energy physicists for elementary particle research.

Monitoring of the quality of the particle beam produced in a new linac (linear accelerator) injector will be the first use for the new computer. Several critical beam diagnostic checks are to be transferred on-line to the GEC 4080 and graphics equipment will be employed extensively.

One important diagnostic check involves wire profile monitors located at various points in the beam path. Wire profile monitors are arrangements of very fine wires, too fine and too widely spaced to violate the beam. The wires become individually charged by the secondary emission resulting from the passage of the beam. Analogue to digital conversion is carried out and the resulting data are now to be mapped on a display by the GEC 4080 which will produce a diagram indicative of certain beam characteristics including its location within the beam tube.

Another of the beam diagnostic procedures to be monitored by the new computer will be the drawing of an emittance diagram—an elliptical pattern indicative of beam quality. Previously this has been produced manually by tracking slotted blanking plates across the beam path. Since the incursion of the plates into the beam path destroys the beam and since many adjustments must be made in order to plot a closed elliptical diagram, this method has been tedious. It will now be possible to produce emittance diagrams much more rapidly by non-destructive means and furthermore, to show these on a quartered graphics display together with the previously referred wire profile, a third performance graph and some narrative. This display will present the laboratory staff with an immediate and comprehensive report on the beam characteristics and quality.

In a few months' time the linac control system will be connected using CAMAC interface modules to the GEC 4080. Data logging control and fault-reporting procedures will then be implemented. Eventually all the *Nimrod* synchrotron control and diagnostic equipment will be connected into the GEC 4080 computer.

The system, valued at nearly £50,000, is composed of 64k byte GEC 4080 processor with paper tape equipment, 2·4 + 2·4Mbyte fixed/exchangeable cartridge disk store, magnetic tape store, dot matrix printer, 11-inch graphical display unit, hard copy printer, two teleprinter-compatible v.d.u.s and various CAMAC interface modules.

Signal Generator Specifications

British Standard 5133 'Specifying the performance of frequency-modulated signal generators' and BS 5134 'Specifying the performance of amplitude-modulated signal generators' describe methods of specifying the performance of signal generators operating in the range 30 kHz to 1000 MHz with substantially sinusoidal frequency modulation and amplitude modulation. Instructions are given in both standards for the measurement and statement of errors in accordance with the general principles set out in BS 4889. Both standards are identical in technical content with International standards IEC 452 and IEC 453 respectively.

Copies of BS 5133 and BS 5134 are available from BSI Sales Department, 101 Pentonville Road, London N1 9ND. Price £2.70 each including postage.

Standard Cells

BS 5142: 1974 'Standard cells' has just been published by the British Standards Institution. Apart from establishing terminology for both saturated and unsaturated standard cells, it specifies a classification for cells having limits of permissible deviation of the e.m.f. during the first year after initial certification between 2 parts/10^5 and 100 parts/10^5. It also specifies the operating temperature range, a range of values within which the certified e.m.f. shall lie, and other electrical and mechanical characteristics such as permissible discharge, insulation resistance and constructional requirements. It does not apply to cells used as international or national standards of e.m.f. This British Standard is identical both in technical content and format to Publication 428, 'Standard cells', of the International Electrotechnical Commission.

BS 5142, price £1.50 including postage, can be obtained from BSI Sales Department, 101 Pentonville Road, London N1 9ND.

Conference on

'Instrumentation in Oceanography'

Organized by THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS with the association of The Institute of Electrical and Electronics Engineers, The Institute of Physics, The Institute of Acoustics, The Institution of Electrical Engineers, The Royal Institute of Navigation and The Society for Underwater Technology.

University College of North Wales, Bangor—23rd to 25th September 1975

Provisional Programme

Tuesday, 23rd September 1975

Welcome by Professor J. W. R. Griffiths, Ph.D., C.Eng., F.I.E.E., F.I.E.R.E.,
Chairman of the Conference Organizing Committee

Opening Address by Dr. J. Birks, C.B.E. of British Petroleum Company Ltd.

OCEANOGRAPHIC SENSORS

'A self-balancing bridge for measuring salinity'
By G. G. Coghill and R. Bowers (*Scottish Marine Biological Association*)

'A salinity and temperature surface profiler'
By J. Moorey (*I.O.S.*)

'Instrumentation for marine dispersion measurements using radioactive tracers'
By C. B. Waters (*Hydraulics Research Station*)

'A pressure sensor probe which is insensitive to velocity primarily designed for tide-gauge use'
By T. J. P. Gwilliam, V. A. Lawford and Dr. R. M. Garson (*I.O.S.*)

Chairman: Dr. B. S. McCartney

'The measurement of Richardson number in the ocean'
By J. H. Simpson and J. Stratford (*University College of North Wales*)

'A deep sea temperature and pressure sensor for tidal measurement'
By T. J. P. Gwilliam (*I.O.S.*)

'A current velocity sensor for an STD system'
By F. N. Mathers (*University of Liverpool*)

'Measurement of turbulence near the sea-bed using electromagnetic current meters'
By A. D. Heathershaw (*Marine Science Laboratories*)

'Ultrasonic measurements of ocean currents down to 1 mm/sec'
By T. Gytre (*Institute of Marine Research, Norway*)

'Underwater logarithmic irradiance meter for primary production studies'
By D. A. Kahn (*Plessey Radar Research Centre*), Dr. M. J. R. Fasham, M. J. Harris and Dr. P. T. Pugh (*I.O.S.*)

'Techniques for measuring the modulation transfer function of turbid waters'
By Dr. B. K. Gazey, Dr. M. Evershed, and S. Develliogl u (*University of Birmingham*)

'The simulation in the laboratory of random seas and their effects'
By D. K. Fryer and M. J. Wilkie (*Hydraulics Research Station*)

Wednesday 24th September 1975

FISHERIES

'Sonar system for fish detection in deep water'
By L. W. Proctor (*Fisheries & Marine Services, Canada*)

'Developments in sector scanning sonar'
By M. Holley and R. B. Mitson (*Ministry of Agriculture*) and Dr. A. R. Pratt (*Loughborough University of Technology*)

'Recent results of marine electrical fishing experiments'
By Dr. A. M. P. Stewart (*Marine Laboratory, Scotland*)

'A low cost quantitative videosignal processor for pelagic fish shoal images derived from aircraft-borne, low-light-level television'
By F. C. Glaum and D. L. Cram (*Sea Fisheries Branch, South Africa*)

'A survey of the engineering problems of developing small acoustic fish tags'
By R. B. Mitson (*Ministry of Agriculture*) and A. H. Young (*University of Stirling*)

'Multichannel telemetry by transponding acoustic tag'
By T. J. Storeton-West (*Ministry of Agriculture*)

'Systems for telemetry from free-swimming fish'
By Dr. D. G. Pincock and D. McG. Luke (*University of New Brunswick*)

'A digital data logging system for acoustic studies of fish stocks'
By I. Hampton and F. C. Glaum (*Sea Fisheries Branch, South Africa*)

DATA ACQUISITION AND TELEMETRY

'A position determination system and data relay'
By Dr. D. J. Phipps, Dr. E. W. Roberts, R. Ll. Prior-Jones, Dr. J. D. Last and Dr. J. H. Simpson (*University College of North Wales*)

'Data handling and power systems for the prototype UK data buoy'
By J. Butcher, B. H. Twist and J. Wall (*Hawker Siddeley Dynamics*)

'Wave data telemetry via the Nimbus-F satellite'
By Dr. C. H. Clayson (*I.O.S.*)

'A deep water trawl headline height telemeter'
By N. D. Pearson and T. J. Storeton-West (*Ministry of Agriculture*)

'An acquisition system for ocean, weather and motion data for a pipelaying-barge'
By M. Brunel (*Comex Equipment, France*)

'A high-rate acoustic telemeter for fish studies'
By Dr. L. N. Lipscombe (*EMI Electronics*)

'A real time wave analysis system'
By J. G. White (*N.B.A. (Controls) Ltd.*)

Thursday, 25th September 1975

SEABED EXPLORATION

'A new sub-bottom profiling sonar using a non-linear sound source'
By P. Pettersen, J. M. Hovem, A. Lovik and T. Knudsen (*Electronics Research Laboratory, Norway*)

(*cont. next page*)

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meeting on 20th May 1975 recommended to the Council the election and transfer of the following candidates. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning the proposed elections must be addressed by letter to the Secretary within twenty-eight days after the publication of these details.

Meeting: 20th May 1975 (Membership Approval List No. 209)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Graduate to Member

BROOKS, John. *Dinas Powys, Glamorgan.*
CURUANA, John Newton. *Bromley, Kent.*
CUTHBERT, Laurence Geoffrey. *Harlow, Essex.*
GOTHARD, Alan. *Fleetwood, Lancashire.*
STEVEN, Robert. *Malvern, Hereford and Worcester.*
WHITE, Brian Stanley. *Southampton, Hampshire.*

Direct Election to Member

BARACLOUGH, John Neale. *Newton Mearns, Glasgow.*
DAVIES, David Alan. *Bournemouth, Dorset.*
HALE, Ronald John. *Fareham, Hampshire.*
WILLIAMS, Daniel Keith. *Camberley, Surrey.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

CLARK, Lorne. *Maidenhead, Berkshire.*
DILLIEN, Paul. *Barking, Essex.*
FITCH, John Lewis. *Barnet, Hertford.*
HIGGINS, Terence Michael. *Brockworth, Gloucester.*
MORSE, John Brian. *Bedford.*

Transfer from Graduate to Associate Member

ROSE, Frank Edwin. *London.*
MENZIES, Malcolm Raymond. *Letchworth, Hertford.*

Transfer from Student to Associate Member

NICHOLSON, Kenneth. *Blyth, Northumberland.*
TOOLEY, Michael Howard. *Weybridge, Surrey.*

Direct Election to Associate Member

BULMER, John Harry. *Crossgate Moor, Durham.*
COLEGATE, Charles Harold. *Thirsk, Yorkshire.*
ROBERTS, Mark Alexander. *Thornbury, Bristol.*
RODRIGUES, Avelino Saturnino. *Greenford, Middlesex.*
RUSSELL, John Maitland. *Wolverhampton, Stafford.*

Transfer from Graduate to Associate

GOOD, Kenneth Harry. *Southsea, Hampshire.*

Transfer from Student to Associate

MORGAN, Cyril Handel. *Aberdare, Mid Glamorgan.*

STUDENTS REGISTERED

GRANDISON, James Robert. *Malvern, Hereford and Worcester.*
KLIMASZEWSKI, Frank Richard. *London W.6.*
LEWIS, David Kenneth. *Coventry.*
TANG, Francis Mark. *Cardiff.*

OVERSEAS

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

GRAVENEY, William. *Salisbury, S. Australia.*

Transfer from Student to Associate Member

AGBOLA, Titus Omotayo. *Potisicum, North-East State, Nigeria.*

Direct Election to Associate Member

TNAY, Si Kiat. *Kuching, Sarawak, Malaysia.*
ZAMMIT, Roger J. *B'Kara, Malta.*

Transfer from Student to Associate

LEONG, Hou Kit. *Singapore.*

STUDENTS REGISTERED

LAW, Chun Hung. *Kowloon, Hong Kong.*
YEE, Sin Choy. *Grik, Perak, Malaysia.*

Correction:

Membership Approval List No. 208, published June 1975

OVERSEAS: NON-CORPORATE MEMBERS

Transfer from Student to Associate Member (*not Student to Associate as shown*)
CHAPSON, Ernest. *Quebec, Canada.*

(*cont. from page 375*)

'A paper recording system for an electronic sector scanning sonar'
By N. D. PEARSON and W. L. HUGGINS (*Ministry of Agriculture*)

'A new electrical method for evaluating the in-situ strength of marine sands'
By P. D. JACKSON (*University College of North Wales*)

'Pump samplers for measuring sand transport in tidal waters'
By M. J. CRICKMORE and R. F. AKED (*Hydraulics Research Station*)

'A miniature transponding pebble for studying gravel movement'
By DR. A. P. DOREY, DR. K. DYER and A. R. FINCH (*University of Southampton*)

NAVIGATION, SURVEYING AND UNDERWATER INSPECTION

'A high resolution within-pulse sector-scanned sonar with electronically variable focussing'
By DR. D. J. CREASEY and J. R. DUNN (*University of Birmingham*)

'Underwater imaging using an ultrasonic image converter tube'
By R. T. CLAYDEN (*EMI Central Research Laboratories*)

'A low-cost synchronised clock technique for underwater instrumentation and navigation'
By R. M. DUNBAR (*Heriot-Watt University*)

'Acoustic instrumentation for powered submersible vehicles'
By H. B. BRAITHWAITE (*University of Birmingham*) and R. NESBITT (*Vickers Oceanics Ltd.*)

'A.N.G.U.S. underwater navigation'
By R. T. HOLMES (*Heroit-Watt University*)

'A mode of operation of a mapping sonar to give explicit corrections for the variation of velocity with depth'
By R. VOLES (*EMI Electronics Ltd.*)

'Hydrographic surveying with electronic sector scanned sonar'
By E. E. ALDRIDGE, D. W. COLVIN, W. O. B. MONKHOUSE and L. D. WARD (*AERE*)

Closing Remarks by PROFESSOR J. W. R. GRIFFITHS, Chairman of the Conference Organizing Committee

IERE Conference Proceedings

Bound Volumes of the following Conference Proceedings are currently available

Number	*Title of Conference*	*Price* £	*Price* U.S. Dollars $
4	**'Signal Processing in Radar and Sonar Directional Systems'** (Birmingham, 1964)	6·00	16·50
5	**'Microwave Applications of Semiconductors'** (London, 1965)	7·00	19·25
7	**'Applications of Thin Films in Electronic Engineering'** (London, 1966)	7·00	19·25
8	**'Electronic Engineering in Oceanography'** (Southampton, 1966)	7·00	19·25
9	**'The Integration of Design and Production in the Electronics Industry'** (Nottingham, 1967)	7·00	19·25
10	**'RF Measurements and Standards'** (Teddington, 1967)	6·00	16·50
11	**'Thick Film Technology'** (London, 1968)	4·50	12·40
12	**'Electronics in the 1970s'** (Cambridge, 1968)	5·20	14·30
13	**'Electronic Weighing'** (London, 1968)	4·50	12·40
14	**'Lasers and Opto-Electronics'** (Southampton, 1969)	7·50	20·65
15	**'Digital Methods of Measurement'** (Canterbury, 1969)	6·00	16·50
16	**'Industrial Ultrasonics'** (Loughborough, 1969)	6·00	16·50
17	**'Automatic Test Systems'** (Birmingham, 1970)	7·50	20·65
19	**'Electronic Engineering in Ocean Technology'** (Swansea, 1970)	7·50	20·65
20	**'Laboratory Automation'** (London, 1970)	7·00	19·25
21	**'Electronic Control of Mechanical Handling'** (Nottingham, 1971)	7·50	20·65
23	**'Digital Processing of Signals in Communications'** (Loughborough, 1972)	7·50	20·65
26	**'Video and Data Recording'** (Birmingham, 1973)	8·00	22·00
27	**'Hybrid Microelectronics'** (Canterbury, 1973)	8·00	22·00
28	**'Remote Control System Organization'** (London, 1973)	2·50	6·90
29	**'Environmental Sensors and Applications'** (London, 1974)	9·00	24·75
30	**'Advances in Automatic Testing Technology'** (Birmingham, 1975)	12·00	33·00

Prices include postage by surface mail

Orders with remittance to the Publications Department

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

8-9 Bedford Square, London WC1B 3RG **Telephone: 01-637 2771 Ext. 19**

The Institution's Specialized and Local Activities

Ever since the Institution was founded in 1925 its stated objectives have been, 'To promote the advancement of radio and electronics and kindred subjects by the exchange of information in these branches of engineering'. These aims are met in many ways: the Institution's Journal, for instance, publishes many technical papers on electronics and allied subjects; the Library and Information Service is available to give help and advice; and the Institution also organizes lecture meetings both nationally and regionally.

In order that Institution members, particularly those who have been recently elected, may know more about some of the services which the Institution provides, this article summarizes the work that is being done by the Specialized Group Committees and by the local Sections. These organizations within the Institution are between them responsible for arranging conferences, symposia, colloquia and evening lecture meetings throughout the greater part of the United Kingdom.

LOCAL SECTIONS IN THE UNITED KINGDOM

Members living in most parts of the country receive information on locally-organized events which usually take the form of evening lectures held in the more accessible cities or towns in the area and also include social functions and technical visits. These functions are organized by Local Section Committees, consisting of Institution members who are elected annually by members at the Section's Annual General Meeting. Each Committee consists of a Chairman—who attends meetings of the Council of the Institution and is thereby kept informed of Institution plans and policies—an Honorary Secretary, a Treasurer, Conveners and other Committee Members, including Graduate and Student representatives.

On joining the Institution any member may freely avail himself of Local Section activities in or near the area in which he lives, and may attend meetings of interest held by other Sections without any special formality. In the past, members have been allocated to Sections according to their registered postal address. For two reasons, this policy is being modified; firstly, because members who live in one area but work in another may often find a neighbouring Section's venue to be more accessible; and secondly, because the new county names and boundaries which became effective in April 1974 have led to some confusion as to the exact areas covered by each Section. This first point is of long standing and applies in particular to those people who work in a city and live in the country; and especially affects members living in some parts of the Home Counties, many of whom may find it more convenient to attend meetings in London.

We are now asking *all* members to let us know which Section they would like to belong to, and at the same time to inform us of their correct postal address, where this has been altered. (The adoption of new county designations, as well as the use of postcodes, is in any case being urged upon users by the Post Office). Local Secretaries will then be informed of changes in the membership of their Sections. Members living outside the South East who wish to receive the London booklet in addition to that for the Section in which they live should write to the Institution separately. The London booklet at present contains London meetings and those of the East Anglian, Kent, Beds and Herts, and Thames Valley Sections.

The boundaries shown on the map opposite are largely based on the new county boundaries and take into account the numbers of members in each area. They are necessarily somewhat arbitrary and are not immutable: alterations can be made if there is sufficient demand and in fact a new Section which has only just come into existence as a result of members' requests is shown.

A minority of members may now find themselves geographically placed in a new Section or even outside any Section. In practice, they will continue to receive information about their previously allocated Section, unless and until the Institution is informed by them to the contrary. (See page (ix).)

There are now sixteen Local Sections in the United Kingdom authorized by the Council, as follows:

SOUTH WESTERN SECTION

Cornwall, Devon, Somerset, the new County of Avon, and Wiltshire. Most meetings in Bath and Bristol; usually twice each Session in both Plymouth and Swindon.

SOUTHERN SECTION

Dorset, Hampshire, the Isle of Wight, Surrey (except that part of Surrey included in the extended Greater London Area), and the new Counties of East and West Sussex. Meetings in Southampton, Portsmouth, Newport (I.o.W.), Brighton, Bournemouth, Weymouth Farnborough and Guildford.

KENT SECTION

The county of Kent excluding that area of Kent which is now part of Greater London. Most meetings in Chatham.

EAST ANGLIAN SECTION

Essex, Suffolk, Norfolk and the newly extended County of Cambridge. Most meetings in Chelmsford, Cambridge and Colchester with occasional meetings at Hornchurch, Ipswich and Norwich.

BEDS AND HERTS SECTION

The two counties indicated by the name are to be covered by this latest Section which will hold its first meetings in Autumn 1975. Meetings are initially planned to be held in Hatfield and Bedford.

THAMES VALLEY SECTION

Buckinghamshire and the slightly altered new areas of Berkshire and Oxfordshire. All meetings in Reading.

SOUTH WALES SECTION

West, Mid and South Glamorgan and Gwent (formerly Monmouthshire). Meetings in Swansea and Cardiff. (Note—Members living outside these areas—e.g. the former Carmarthenshire, now part of Dyfed—will automatically be kept in the Section).

SOUTH MIDLAND SECTION

The counties of Hereford and Worcester, and Gloucester. Meetings in Evesham, Gloucester, Cheltenham, Malvern and other occasional centres.

WEST MIDLAND SECTION

Salop, Stafford, Warwick and the new West Midlands county. Meetings in Wolverhampton, Coventry, Birmingham and other occasional centres.

EAST MIDLAND SECTION

The newly extended county of Leicester, and the counties of Northampton, Derby, Nottingham and Lincoln. Most meetings in Loughborough or Leicester with occasional ones at Nottingham and Cranwell.

Note.—Members whose addresses are in Greater London or the area marked 'Wales' are not automatically associated with a Local Section, but of course may opt to belong to any of the Sections.

MERSEYSIDE SECTION

The new Metropolitan county of Merseyside, the greater part of Cheshire (west of Crewe—see map) and the newly formed county of Clwyd in North Wales. All meetings in Liverpool.

NORTH WESTERN SECTION

Lancashire, Greater Manchester and the area of Cheshire east of Crewe (see map). All meetings in Manchester.

NORTH EASTERN SECTION

The newly formed or altered counties of Cumbria, Northumberland, Tyne and Wear, Durham and Cleveland. All meetings in Newcastle-upon-Tyne.

YORKSHIRE SECTION

The former county of Yorkshire (now North, West and South Yorkshire, and Humberside), but excluding the new county of Cleveland. Meetings in Bradford, Leeds, Huddersfield, Wakefield, York and Hull.

SCOTTISH SECTION

All Scotland. Meetings in Edinburgh and Glasgow; occasionally other venues.

NORTHERN IRELAND SECTION

All Northern Ireland. Meetings in or near Belfast.

SPECIALIZED GROUPS

The majority of the colloquia and conferences which are organized on a national basis are promoted by one or other of the Specialized Group Committees, and the programme is coordinated by the Professional Activities Committee.

The following terms of reference are common to all the Specialized Groups:

(a) To promote Institution activities within their agreed fields of interest by arranging meetings and procuring papers for publication—both in collaboration with the Professional Activities Committee and the Papers Committee of the Journal.

(b) To collaborate with other bodies and committees, both internal and external, for the purpose of advancing and disseminating knowledge of their specified field of interest.

(c) To collaborate with the Professional Activities Committee to promote the preparation and acceptance of relevant standards and codes of practice and to provide specialist guidance to the Institution representatives on BSI Committees.

All members, irrespective of grade, are entitled to attend meetings arranged by any of the Groups, and details of these meetings are announced in the Journal and in the London programme booklet. Additional information may become available about particular Group meetings which cannot be publicized in these ways and this will be sent automatically, and free of charge, to those members who have advised the Institution of their areas of interest by appropriately marking and returning the form on page (ix).

Aerospace, Maritime and Military Systems (AMMS)

This Group extended (in 1968) the scope of the former Radar & Navigational Aids Group, set up in 1960, to include instrumentation and communications systems for aerospace, sea and land vehicles.

Fields of interest: Radar and navigation systems; sonar; control and guidance; instrumentation for aerospace, sea and land vehicles; communications systems for aerospace, sea and land vehicles.

Automation and Control Systems (ACS)

The Automation and Control Systems Group was formed in 1972 from the original Instrumentation and Control Systems Group, founded in 1968. It had become apparent that the topics which the latter embraced fell into two distinct areas:—'automation and control' and 'measurements and instruments'—and would be best served separately. The Automation and Control Systems Group was then formed and the Measurements and Instruments Group was set up in 1975.

Fields of interest: Systems, techniques and components used in automation and control, namely systems theory, automation and control applications; systems applications of transducers and sensors; industrial electronic power sources; design office automation, automation of testing, system integrity, management of automation; man-machine systems; system performance measurement, special and general purpose computers.

Communications (Com)

First set up in 1961, as the Television Group, this Group was widened in 1968 to embrace new areas of communications techniques.

Fields of interest: Television and sound broadcasting, recording and reproduction; switching and distribution systems and links for sound, vision and data; aerials, propagation and guided waves.

Components and Circuits (CC)

This Group came into being in 1968, as a result of the need for a specialized group to cover both the technological aspects of the newer types of electronic component such as integrated circuits, and the advances in development of the more conventional components such as resistors and capacitors.

Fields of interest: Fundamental physics; design, manufacture and applications of components and circuits, including materials; physical electronics; circuit theory; components—active and passive, integrated circuits; microwave and optical devices, filters, transducers.

Computer (Comp)

The Computer Group was formed in 1958 to cope with the demand for discussion and dissemination of knowledge relating to the new computer technology which was then just emerging. All meetings are organized jointly with the IEE.

Fields of interest: Electronic computers, associated equipment and techniques.

Education and Training (ET)

The Education and Training Group exists to provide a forum where members directly involved in education or interested in developments in education and training policy, particularly as they affect the professional engineer, can exchange ideas and be provided with organized opportunities for being informed of current trends and developments.

Fields of interest: Methods of teaching and training, the organization of courses, trends in education and new fields of education having a bearing on electronic engineering.

Medical and Biological Electronics (MBE)

The Medical and Biological Electronics Group was formed in 1958 to organize meetings on the application of

electronics in the medical field. Initially, it concentrated on applications made possible by the development of miniaturized components, but its interests have subsequently broadened very considerably. All meetings are held jointly with the corresponding Professional Group of the IEE.

Fields of interest: Electronic techniques applicable to any branch of medical or biological science.

Measurements and Instruments (MI)

This Group came into being as a result of the division of the Instrumentation and Control Systems Group, and its Inaugural Meeting was held in April 1975.

Fields of interest: Measurement theory, practice and applications; standards and calibration; transducers and sensors, theory, practice and applications; instrument physics; generation of stimuli, quantities and test signals; engineering design of instruments; programmable instruments.

Other Groups

In 1968 a Group on **Management Techniques (MT)** was set up and several sessions of meetings have been held. Recently, proposals have been made for a further Group, to cover **Electronics Production Technology (EPT),** and exploratory discussions on its scope have taken place. These indicated that there could be substantial areas of overlap between the two Groups, or indeed with other Groups, and it is proposed to investigate the best way in which the Institution could cover these subjects. In order that the Professional Activities Committee can assess the likely support, members are invited to indicate on the form their probable interest in meetings on these subjects.

NOTICE TO ALL MEMBERS IN THE UNITED KINGDOM

It would greatly assist the Membership Department and expedite the delivery of Journals and other correspondence if ALL MEMBERS would indicate their current interests and address below, including their new county boundaries and postal codes. We are also asking members to use this form for CHANGES OF ADDRESS (Reprints will be available on request). NEW MEMBERS are also requested to complete this form.

Name..... Grade of Membership .....
(including title, qualifications, etc.) (Block Capitals Please)

Address .....

.....

County..... Postal code .....

Local Sections *(see page (vi))*

My present Local Section is.....

I would like to be transferred to the.....Section

Specialized Groups *(see page (viii))*

I would like to be sent information on events organized by the following Groups:

Please tick as appropriate (*maximum three*)

- ☐ Aerospace, Maritime and Military Systems (AMMS)
- ☐ Automation and Control Systems (ACS)
- ☐ Communications (Com)
- ☐ Components and Circuits (CC)
- ☐ Computer (Comp)
- ☐ Education and Training (ET)
- ☐ Medical and Biological Electronics (MBE)
- ☐ Measurements and Instruments (MI)
- ☐ Electronics Production Technology (EPT)
- ☐ Management Techniques (MT)

I am a member of the following IERE Committees.....

Signature..... Date.....

Please complete and return to: The Membership Secretary, IERE, 8–9 Bedford Square, London WC1B 3RG.

Conferences, Courses and Exhibitions, 1975-76

The date and page references in italics at the head of an item are to issues of *The Radio and Electronic Engineer* in which fuller notices have been published. An asterisk (*) indicates a new item or information which has been amended since the previous issue. The symbol (●) indicates that the IERE has organized the event or is a participating body.

Further information should be obtained from the addresses given

1975

August 17–22 EDINBURGH *March 1974, p. 177*
5th International Conference on Recent Advances in Bio-Medical Engineering (BES)
Mr. K. Copeland, Biophysics Department, University College London, Gower Street, London WC1E 6BT

August 25–29 SYDNEY, N.S.W.
International Electronics Convention '75
The Institution of Radio and Electronics Engineers, Australia, 157 Gloucester Street, Sydney, N.S.W. 2000

August 27–September 3 GUILDFORD
137th Annual Meeting of the British Association
BAAS, 23 Savile Row, London W1X 2AA (Tel. 01-734 6010)

August 29–September 7 BERLIN
International Radio and TV Exhibition 1975
Mr. W. Zahn, German Chamber of Industry & Commerce, 11 Grosvenor Crescent, London SW1X 7EE (Tel. 01-235 9947); AMK Berlin, D 1000 Berlin 19, Messedamm 22 (Tel. (030) 3038-1)

● September 1–4 HAMBURG *March 1975, p. 145*
5th European Microwave Conference
Dr. H. J. Schmitt, Philips Forschungslaboratorium Hamburg, D2 Hamburg 54, Vogt Koellnstrasse 30, Germany

● September 2–4 OXFORD *October 1974, p. 572*
2nd National Quantum Electronics Conference (IoP, IERE, IEE, Chem. Soc.)
Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QZ (Tel. 01-235 6111)

● September 2–5 CANTERBURY, KENT *March 1975, p. 145*
1st European Solid State Circuits Conference (ESSCIRC) (IEE, IERE, IoP and others)
Conference Department, IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

September 8–12 GRENOBLE, FRANCE
European Solid State Device Research Conference (ESSDERC) (IoP, EPS)
Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QZ (Tel. 01-235 6111)

September 8–13 CRACOW, POLAND
4th International Conference of Women Engineers and Scientists—New Techniques in the Service of Mankind
Mrs. Isabel Hardwich, International Correspondent Women's Engineering Society, 75 Irlam Road, Urmston, Manchester M31 3JU

● September 9–11 LOUGHBOROUGH
Conference on Hybrid Microelectronics (IERE, IEE, IoP, ISHM, IEEE)
IERE, 8–9 Bedford Square, London WC1B 3RG (Tel. 01-637 2771)

● September 9–11 LONDON
Conference on Telecommunication Transmission
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

September 9–11 NOORDWIJKERHOUT, THE NETHERLANDS
International Conference on Physical Aspects of Noise in Solid State Devices
Dr. G. M. Kleinpenning, Department of Electrical Engineering, University of Technology, P.O. Box 513, Eindhoven, The Netherlands

September 9–12 CARDIFF
12th Annual Conference on Non-Destructive Testing
The Non-Destructive Testing Society of Great Britain, Maitland House, Warrior Square, Southend-on-Sea, Essex SS1 2JY

September 9–13 BASLE, SWITZERLAND
Exhibition of Industrial Electronics and Electrical Engineering
Schweizer Mustermesse Basel, 4021 Basel, Switzerland

September 10–17 BIRMINGHAM
Vacation School on Switching and Signalling in Telecommunications Networks
IEE, LS(P), Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

September 16–18 LONDON
Automatic Testing 75 Exhibition and Seminar
Network, 84 High Street, Newport Pagnell, Bucks MK16 8EG (Tel. (0989) 610798)

● September 16–19 LONDON
Conference on Optical Fibre Communications (IEE, IERE)
Conference Department, IEE, Savoy Place, London WC2R 0BL

September 16–19 SAN FRANCISCO
IEEE Wescon—Western Electronics Convention and Exhibition
IEEE Intercon, 3600 Wilshire Boulevard, Los Angeles, Calif. 90010

September 16–20 MUNICH
Productronica 75—International Conference and Exhibition for Electronics Production
Münchener Messe- und Ausstellungsgesellschaft mbH, D-8000 München 12, Messegelände, P.O.B. 12 10 09 (Tel. (089)76 71-229)

* September 18–21 CAMBRIDGE
3rd Royal Television Society Bi-annual Convention
Mr. D. Gurton, Royal Television Society, Tavistock House North, Tavistock Square, London WC1H 9HR (Tel: 01-387 1970/1332)

September 22–26 LONDON
International Engineering Conference—150th Anniversary of Passenger Railways (ICE, IMechE, IEE, IRSE)
Secretary, Railway Division, Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1H 9JJ

September 22–26 JOHANNESBURG
9th Instrument and Automation Exhibition (SAIMC)
British Joint Venture and Seminar: W. Pickett, BEAMA, 8 Leicester Street, London WC2H 7BN (Tel. 01-437 0678)

● September 23–25 BANGOR *August 1974, p. 449*
Conference on Instrumentation in Oceanography
IERE, 8–9 Bedford Square, London WC1B 3RG (Tel. 01-637 2771)

September 24–October 2 AMSTERDAM
HET Instrument 1975
Het Instrument, P.O.B. 152, Soest, Netherlands

September 29–October 1 TORONTO
International Electrical, Electronics Conference and Exposition
IEEE Canadian Region Office, 7061 Yonge Street, Willowdale, Ontario.

September 30–October 1–2 LONDON
Electronics Displays 75 Exhibition and Conference
Network, 84 High Street, Newport Pagnell, Bucks, MK16 8EG (Tel. (0908) 610798)

October 1–3 TURIN
Elettronica 3—Third International Exhibition of Industrial Electronics
Convegno Internazionale di Elettronica Industriale, Corso Massimo d'Azeglio 15, 10126, Turin, Italy (Tel. 65069)

October 2–8 GENEVA
2nd World Telecommunication Exhibition and Forum, Telecom 75 (ITU)
Secretariat-general TELECOM 75, 18, Quai de l'Ecole-de-Médecine, 1211 Genève 4, Switzerland

October 6–10 GOTHENBURG
4th International Trade Fair for the Electrical Engineering Industry —ELFACK
Joint Venture BEAMA/BOTB: W. Pickett, BEAMA, 8 Leicester Street, London WC2H 7BN

October 10–16 COPENHAGEN
Elektronik 75
Press Dept., Bella Centret, 64 Hvidkildevej, DK–2400 Copenhagen NV Denmark

October 14–16 BRUSSELS
Second International Symposium on CAMAC in Computer Applications (ESONE Committee)
Dr. H. Meyer, c/o Commission of the European Communities C.R.C.-CBNM, Steenweg naar Retie, B-2440 Geel, Belgium

October 18–24 BAHRAIN
Exhibition on Engineering and Bahrain; Seminar on Engineering and Development in the Gulf
The Organizers, P.O. Box 551, Bahrain

* November 3–5 ZURICH
Semicon/Europa 75 Trade Fair
Semicon/Europa, C/o I. Willener, CH-8001, Zurich, Lindenstrasse 33, Switzerland

November 3–7 PARIS
International Conference on Biomedical Transducers
FNIE, 16 Rue de Presles, 75740 Paris, Cedex 15

● November 4–7 LONDON
Conference on Piezoelectric and Pyroelectric Materials and Applications (IEE, IERE, IoP, IAE, IEEE)
Conference Department, IEE, Savoy Place, London WC2R 0BL

November 10–14 MANCHESTER
Automated Production Exhibition
Exhibitions for Industry Ltd., 157 Station Rd. East, Oxted RH8 0QF, Surrey

November 18–20 TEDDINGTON, MIDDLESEX *May 1975, p. 256*
Conference on Civil Land Mobile Radio (IERE, IEEE)
IERE, 8–9 Bedford Square, London WC1 3RG

November 18–20 LONDON
Conference on Electrical Methods of Machining, Forming and Coating
Conference Department, IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

November 20–30 SAO PAULO, BRAZIL
1st International Mechanical Engineering and Electro-Electronics Trade Fair
British Joint Venture: W. Pickett, BEAMA, 8 Leicester Street, London WC2H 7BN (Tel. 01-437 0678)

November 25–29 BRUSSELS
21st Interélectronique
Union Professionnelle des Fabricants et Importateurs de Matériel Electronique, 74 Avenue Molière, 1180 Bruxelles (Tel. 345 7129)

● December 1–4 LONDON
Conference on Signal Filtering
(IEE, IERE, IoP, IEEE)
Conference Department, IEE, Savoy Place, London WC2R 0BL

December 9–11 LONDON *October 1974, p. 572*
2nd International Conference on Electrical Safety in Hazardous Environments
Conference Department, IEE, Savoy Place, London WC2R 0BL

1976

January 5–7 MANCHESTER
13th Annual Solid State Physics Conference
Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QX (Tel. 01-235 6111)

● March 30–April 1 LONDON
Conference on Small Electrical Machines
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

● April 6–8 SOUTHAMPTON
Conference on Applications of Electronics in Medicine (IERE, IEE, BES)
IERE, 8–9 Bedford Square, London WC1B 3RG

* April 11–14 THE HAGUE
Symposium on Marine Traffic Systems
Secreteriat SMTS, c/o Netherlands Maritime Institute, P.O. Box 25138 Rotterdam, The Netherlands

April 13–15 LONDON
The All-Electronics Show
Evan Steadman, 34–36 High Street, Saffron Walden, Essex CB10 1EP

● April 27–30 LONDON
2nd International Marine Exhibition (IMEX 76) and International Marine Shipping Conference (IMAS 76)
(British Marine Equipment Council, IMarE)
Brintex Exhibitions Ltd., 178–202 Great Portland Street, London W1N 6NH

● May 3–7 LONDON
2nd International Symposium on Subscriber Loops and Services (IEE, IEEE, IMA, IERE, IMechE)
IEE Conference Department, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

May 4–8 BIRMINGHAM
International Instruments, Electronics and Automation Exhibition and Electrex Exhibition (EEA, BEAMA & Others)
Industrial & Trade Fairs, Redcliffe House, Blenheim Court, Solihull, West Midlands B91 2BG

May 10–14 LONDON *January/February 1975, p. 88*
VIIth Congress of the International Measurement Confederation (IMEKO)
Mr. S. S. Carlisle, Institute of Measurement and Control, 20 Peel Street, London W.8

May 11–24 BOSTON
Electro/76
IEEE, 3600 Wilshire Boulevard, Los Angeles, California 90010

May 17–21 ROTTACH-EGERN, FRG
7th IFAC Symposium on Automatic Control in Space
VDI/VDE-GMR, P.O. Box 1139, D-4000 Düsseldorf 1, FRG

May 22–26 BRUSSELS
3rd International Exhibition on Instrumentation and Automation Techniques—'Euromation'

May 23–27 BIRMINGHAM
International Home Electronics and Domestic Appliances Exhibition (AMDEA, BREMA)
Andry Montgomery Ltd., 11 Manchester Square, London W1M 5AB (Tel. 01-486 1951)

May 24–26 BRUSSELS
3rd International IFAC Conference on Instrumentation and Automation in the Paper, Rubber and Plastics Industries—'P.R.P. Automation'
BIRA, Jan Van Rijswijcklaan 58, B-2000 Antwerp, Belgium (Tel. (03) 38 65 24)

June 8–11 BRIGHTON
Communications 76—Third International Exposition of Communications Equipment and Systems
Tony Davies Communications Ltd., 1 Victoria Terrace, Ealing Green, London W5 5QS (Tel. 01-579 5941)

June 15–19 DUSSELDORF
3rd International Conference and Exhibition—Interocean '76
NOWEA, Zentralbereich Inland 1, D-4000 Düsseldorf 30, Postfach 320 203, FRG (Tel. (0211) 4560-1)

June 21–25 CAMBRIDGE
Conference on On-Line Operation and Optimisation of Transmission and Distribution Systems
Conference Department, IEE, Savoy Place, London WC2R 0BL

● June 28–July 2 CAMBRIDGE
Golden Jubilee Convention
IERE, 8–9 Bedford Square, London WC1B 3RG

July 5–8 LONDON
International Conference on Automobile Electronics
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

August 3–6 TORONTO
Third International Conference on Computer Communication (ICCC)
Dr. Pramode K. Verma, Program Chairman, ICCC-76, P.O. Box 365, Station 'A', Ottawa, Ontario, Canada K1N 8V3

August 30–September 3 EINDHOVEN
Summer School on Electromagnetics and Antennas
Ir. E. J. Maanders, Electrical Engineering Department, Eindhoven University of Technology, PO Box 513, Eindhoven, The Netherlands

September 1–3 LONDON
2nd Conference on Advances in Magnetic Materials and their Applications
(IEE, IERE, IoP, IEEE)
Conference Department, IEE, Savoy Place, London WC2R 0BL

●September 20–24 LONDON
International Broadcasting Convention—IBC 76
(IEE, IERE, EEA, RTS, etc)
IBC, c/o Savoy Place, London WC2R 0BL

November 9–12 LONDON
International Conference on Millimetric Waveguide Systems
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

November 22–25 LONDON
International Conference on the Future of Aircraft All-Weather Operation
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

HM/4

International Conference on 'Hybrid Microelectronics'

LOUGHBOROUGH — 9th to 11th SEPTEMBER, 1975

Joint Conference Secretariat, IERE,
8-9 Bedford Square, London WC1B 3RG.

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IO/4

International Conference on 'Instrumentation in Oceanography'

BANGOR — 23rd to 25th SEPTEMBER, 1975

Joint Conference Secretariat, IERE,
8-9 Bedford Square, London WC1B 3RG.

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Conference on

'Instrumentation in Oceanography'

Organized by THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS with the association of The Institute of Electrical and Electronics Engineers, The Institute of Physics, The Institute of Acoustics, The Institution of Electrical Engineers, The Royal Institute of Navigation, and The Society for Underwater Technology.

University College of North Wales, Bangor

Tuesday, 23rd to Thursday, 25th September 1975

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